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THE PHYSIOLOGICAL REQUIREMENTS FOR SURVIVAL RATIONS

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UNITED STATES AIR FORCE

AIR MATERIEL COMMAND

Wright-Patterson Air Force Base

Dayton, Ohio

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Date: 3 November 1948

UNITED STATES AIR FORCE
AIR MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE
DAYTON, OHIO

TECHNICAL REPORT
NO. 5740

THE PHYSIOLOGICAL REQUIREMENTS FOR SURVIVAL RATIONS

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I. ACKNOWLEDGEMENT

The author wishes to express his appreciation to the investigators studying related problems under contract with the Quartermaster Food and Container Institute for inspiring the initiation of the present group of studies and for helpful suggestions concerning experimental procedures. I wish to thank Dr. James L. Gamble for numerous thought-provoking discussions and skillful guidance and for permission to use his data on the pure carbohydrate ration. I wish likewise to express my gratitude to Dr. A. C. Ivy for giving me the benefit of his experience and broad fund of knowledge during frequent visits in the course of these investigations. My thanks are due to Colonel E. J. Kendricks and Lt. Col. A. P. Gagge for the opportunity of conducting these studies, their interest and encouragement. To my colleagues, Lt. John Frantz and Capt. George Mellinger, I express grateful appreciation for their assistance in the preparation of this manuscript. I am grateful also to the technicians, especially Miss Dorothy Leffel and Miss Margaret Jackson, who have labored unselfishly to provide the comprehensive laboratory data; Dr. Nathan Talbot for performance of the adreno-cortical hormone analyses; and to Dr. J. W. Wilson and Capt. J. A. Wood for the Haldane analyses. Acknowledgement is made to Dr. W. Franklin Dove for the analysis of the acceptability studies on the second "developmental" emergency ration. I want especially to acknowledge my indebtedness to the experimental subjects who have made it possible for me to acquire personal experience and knowledge without which this report could never have been presented.

II. SUMMARY AND CONCLUSIONS

The statements which follow are conclusions drawn from theoretical considerations, related studies of other investigators, and from the experiments herein reported.

1. Emergency Rations are one of many integral components of aircrew survival equipment. The chances for survival of a castaway depend upon his ingenuity in meeting hostile circumstances, upon his morale and fortitude, and upon the integration of such factors as: protection against the environment, equipment to facilitate rescue, water and water-providing apparatus, injury or sickness, the necessity for energy expenditure and lastly food.

2. Indoctrination in the use and care of survival equipment (including clothing) is as important as their provision aboard aircraft. Instruction in the prevention and management of the physiological problems encountered in survival, and in the most advantageous use of water and rations is essential.

3. Acceptability, storage stability, nutritional adequacy and field utility are the major considerations in ration design and development. An emergency ration must be palatable. It should not be too sweet, too strong or artificial in flavoring or thirst provoking, and it must not induce or aggravate nausea with its continued ingestion. It should be edible at extremes in temperature (-50° to +120°F) and swallowed easily with a restricted free water supply. It should not require cooking for its consumption.

The importance of acceptability in formulating a ration cannot be too strongly emphasized. If a ration component is not acceptable to a soldier under the circumstances for which it is intended and he discards it, then that ration has no value to him regardless of its chemical and biological assay values. If the ration takes the form of a familiar food item, rather than a highly processed unnatural product, he is more likely to eat it and like it.

4. If there is a limitation in weight and space allowances aboard aircraft for both food and water, the advantages of a survival ration must be appraised in terms of its cost to water balance. Survival expectancy is several times longer for fasting than for thirsting. The cost to water balance must be considered from the standpoint of mechanical displacement of water from survival equipment by a larger ration and from the physiological

effects of the ration as reflected in the minimum renal water requirement and body water expenditure. This consideration is particularly true in those environmental circumstances where water is the limiting factor to survival.

5. <u>There is currently no single emergency ration that can satisfactorily meet minimum survival requirements for all geographical areas</u>. Approximately 100 grams of carbohydrate is satisfactory for the Tropics, but its adequacy for the arctic environment has not been established. This amount of carbohydrate favors water balance by reducing the minimum urine water requirement through its sparing of body protein and anti-ketogenic effect when caloric expenditures are only slightly above basal (2000 calories). The question that remains unanswered is - should the survivor be provided with more than 100 grams of carbohydrate per day to prevent ketosis and the physical inefficiency incidental to a marked caloric expenditure associated with the arctic environment?

6. <u>Food is of secondary importance to the adequacy of clothing and sleeping bag for survival at low ambient temperatures</u>. When adequate environmental protection is provided in the form of clothing and a sleeping bag, such that man's caloric expenditure is equivalent to that observed at normal room temperature, the total urine solutes, urine nitrogen and minimum urine water requirement, as well as physical capacity and psychomotor performance are not influenced by a cold environmental temperature. Under the conditions of the present studies, the only significant exposure to the cold was in the inspired air. The normal 11-oxycorticosteroid assays reflect the functional adequacy of the insulation provided and the consequent lack of environmental stress.

7. <u>The minimum water intake necessary to prevent dehydration during fasting is approximately 900 cc per 70 Kg. man per day</u>. This requirement was computed for the conditions of the cold chamber at -29°C and when the daily caloric expenditure was approximately 2800 calories. This value is in good agreement with the estimations of Benedict, Gamble and Ivy for normal environmental conditions and with mild physical activity. However, adverse environmental circumstances (hot, dry) may greatly increase the extra-renal water losses and 900 cc of water would be inadequate to prevent dehydration.

8. <u>A ration containing a small amount of high quality protein does not increase the solute load presented to the kidneys above that associated with fasting if the caloric intake is adequate.</u> The amounts of urinary nitrogen, salts, and ketone bodies are determining factors in the obligatory renal water requirement:

a. The level of urinary nitrogen depends upon a number of interrelated factors; for example, caloric intake and caloric

deficit, absolute quantity of protein intake, quality of dietary protein with respect to its content of the essential amino acids, availability of certain members of the vitamin B complex, and possibly the fat content of the diet. If the source of dietary protein is of high quality, and if sufficient non-protein calories are available or the caloric deficit not too great, the protein content of a ration may be utilized to spare body protein in an amount beyond that of carbohydrate alone so that the urinary nitrogen level does not rise above that of fasting.

b. Despite the high order of acceptability and the favorable effect upon morale, bouillon does not appear eligible for inclusion in an emergency ration because of its high salt content. The sodium chloride, creatimine and other extractives present in a single bouillon cube are equivalent to an increase of 110 milliosmoles in the solute load, or an increase of 80 cc in the renal water requirement.

c. The ketone bodies accompanying starvation ketosis contribute materially to the expenditure of water by the kidneys. With caloric output slightly above the basal level, 100 grams of carbohydrate is capable of preventing ketosis. An emergency ration to be used for survival in the arctic environment must be sufficiently antiketogenic so as to prevent acidosis when the caloric expenditure is marked (4500 calories).

9. Apparently no more than 1000 calories are necessary to maintain physical capacity, as measured by the Harvard step test, for a period of 10 days under the environmental conditions of these studies. If in an experiment in progress, 400 calories (100 grams of carbohydrate) proves to be adequate in preventing ketosis and physical deterioration and maintains morale when caloric expenditure is marked, a single "all-purpose" survival ration would then be available for all geographical areas.* However, if more than 400 calories are necessary, the following ration would appear to warrant consideration as an emergency source of food:

a. 1000 calories per day for the arctic environment and 500 calories per day for tropical areas.

b. Nutrient composition: essentially a carbohydrate ration with small amounts of protein (up to 5 grams) and fat (up to 10 per cent of the calories) as is necessary to obtain maximum palatability and continued acceptability.

c. Accessory items: candy coated gum, sugar cubes, soluble tea product and water purification tablets.

d. Packaged in an hermetically sealed tin containing a ration supply for 2 man days in the arctic (1000 calories per day), or 4 man days in the tropical environment (500 calories per day).

10. The supply and physiological requirement of water may present as much of a problem in the arctic as in the tropical environment. Arctic survival kits should provide a one-burner gasoline stove with a supply of gasoline fuel adequate to melt ice and snow equivalent to 800 cc per man per day for a minimum of 10 days. Tropical survival kits should contain sufficient canned water and water providing appartus (desalting kits, solar stills, rain paulins) to yield a minimum of 800 cc water per man per day for 10 days.

11. If sufficient space is not available for its inclusion in survival kits, a ration providing approximately 2000 calories per day (USAF - ER-2) derived from 50 grams of high quality protein, 75 grams of fat and the remainder from carbohydrate is recommended for use in rescue kits.

12. The following observations and conclusions were made incidental to the studies herein reported:

a. Observations of respiratory quotients suggested that fat metabolism is accelerated during exercise in fasting subjects. A significant increase in energy expenditure for a standard work load (treadmill, 2.5 mph, level) in the cold is attributed to the hobbling effect of the arctic clothing.

b. Errors may be introduced in the determination of the freezing point of urine by the following: (a) changes in osmotic activity as the result of dilution; (b) precipitation of solutes due to temperature-solubility relationships; (c) concentration of the solution due to excessive ice formation; and (d) intrinsic errors of technique. From the standpoint of a physical chemical determination, the measurement of ΔT_f should be made on diluted urine. However, the kidney can remove a given solute load with less osmotic work by eliminating more undissociated molecules and fewer ions. Thus, as a physiological measurement, the ΔT_f should be determined on undiluted urine. How much error is thus introduced by deviation of the molal freezing point depression constant (K_f) from the value 1.86 is unknown.

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*This experiment has been completed since preparation of this report and is described in detail in Engineering Division Memorandum Report No. MCREXD-691-3J entitled "Survival Ration, Arctic, Carbohydrate". In summary, this experiment and a subsequent one have shown that 100 Gm. of carbohydrate is probably adequate for arctic survival.

III. INTRODUCTION

SHALL THE USAF MAKE PROVISION ABOARD AIRCRAFT TO SUPPORT THE CHANCES FOR SURVIVAL OF A CASTAWAY? An affirmative answer is dictated by the American evaluation of human life. Morale and combat efficiency are augmented by the courage and confidence arising from the knowledge that the best available survival equipment is aboard the aircraft and that every effort will be made to facilitate rescue. These psychological factors are essential to the "reckless spirit" necessary in combat to assure delivery of the bomb load on the target — and not in the ocean ten miles away from the base. Because of the relatively large investment made in the training of pilots and other aircrew members, it would not be good business to abandon the castaway with his "ditched" aircraft by neglecting to provide adequately for emergencies with survival equipment and rescue facilities. Thus, for philosophical, psychological and economic reasons, the USAF should make provision aboard aircraft to support the chances for survival of a castaway.

TO WHAT EXTENT SHALL PROVISION BE MADE TO SUPPORT A CASTAWAY? FOR HOW LONG? If the objective of such support is to increase the chance for survival and prolong its probability, then such supportive provision should be defined and limited only by "minimum" physiological needs. In the past aircraft were designed to accomplish delivery of its "pay load" of bombs, and attempts were made to adapt man to the existing engineering limitations of the aircraft. The ability of engineers is being taxed more heavily with the current concept that aircraft must be designed according to the physiological limitations of man. It is easier to re-construct aircraft than to re-construct man. Thus, weight and space allowances for food and water in survival equipment should be defined by the medical man and limited by physiological needs — not by the amount of space in aircraft that remains unoccupied with other essential equipment.

For how long then shall food and water in a quantity to meet "minimum" physiological needs be provided? Survival periods vary widely and chiefly with the theater of operations. Castaways were picked up in less than 24 hours in 97% of those recovered from the English Channel (1). Whereas, average survival periods in the SW Pacific approached 5 to 7 days before rescue was accomplished. Weather conditions in the arctic areas may delay rescue attempts so that survival periods might have to be extended to 10 or 14 days. There are reports on record of castaways who have survived 60 or more days adrift in the Pacific Ocean (2). The exact period for which provisions should be made available in survival kits has been arbitrarily set at 10 days to be consistent with observed average survival experiences and yet practical.

WHAT ARE THE "MINIMUM" PHYSIOLOGICAL NEEDS FOR SURVIVAL? To relate the role of rations in the total picture of survival, a few of the factors upon which survival of a castaway depends are presented. The chances for survival of an aircrew member depends upon his ingenuity in meeting hostile circumstances upon his morale and fortitude, and upon the integration of such factors as: protection against the environment, equipment to facilitate rescue, water and water-providing apparatus, injury or sickness, the necessity for energy expenditure, and lastly food. The physiological inter-relationships among these factors are so closely knit that it is impossible to consider one without the others (Chart 1). The survivor may be subjected to such natural or physiological hazards as exposure to sea water, wind, waves, cold or sunshine, fatigue and exhaustion, motion sickness, dehydration, electrolyte imbalance and ketosis, pre-renal azotemia, deterioration in physical efficiency and morale, disturbances in the maintenance of body thermal equilibrium, and others. A fractured leg may prevent the survivor from altering his immediate environment or otherwise taking care of himself. Food provides energy for the maintenance of body heat, the performance of useful work, basal metabolic processes and may be stored in the form of fat, glycogen and "labile" protein depots. "Dehydration exhaustion" (3) and operational inefficiency caused by marked caloric deficiency with a high work output (4), emphasize the role of water and food respectively in the prevention of physical deterioration. Water and food are essential to the maintenance of morale, both psychologically and physiologically (5). The hallucinations and aimless wanderings of acute dehydration may cost the castaway his life. Diarrhea or intractable emesis from seasickness may upset fluid and electrolyte balances so as to be incapacitating or even fatal.

MAN CAN SURVIVE FASTING SEVERAL TIMES LONGER THAN THIRSTING (6). Thus, water is a limiting factor to survival. Water and salt requirements vary tremendously, depending upon environmental conditions and the heat and work loads. Man can endure a lot of physical hardship, but lack of water is an extremely serious handicap to him. He never can learn to get along without it no matter how often he is exposed to dehydration; neither can he be trained to reduce his water requirements (7). It must be remembered that water supply can be a real problem in the Arctic. Melting ice or snow in the mouth is injurious to the oral mucous membrane and is uneconomical from the standpoint of energy balance. Body heat would be lost to obtain water in this way. Water supply in the Arctic may thus be limited by fuel supply, wood or gasoline. Likewise, water losses may be great in the arctic area where the survivor unwisely permits himself to sweat profusely because of failure to take off or loosen clothes when working strenuously.

If the aircraft has crashed in the frigid Arctic, the greatest concern is protection against the cold environment. A carload of food would not effectively help unless the castaway has adequate

CHART 1

SURVIVAL OF A CASTAWAY
DEPENDS UPON THE INTEGRATION OF

1 — PROTECTION AGAINST ENVIRONMENT

SHELTER
1. TENT
2. LIFE RAFT
   - CANOPY
   - AIR MATTRESS
   - REPAIR KIT
3. LOCAL SOURCES
   - LEAN-TO
   - IGLOO

CLOTHING
1. FLYING CLOTHES
2. ANTI-EXPOSURE
3. PARACHUTE
4. LIFE PRESERVER
5. SLEEPING BAG

SOURCES OF HEAT
1. STOVES
   - GASOLINE
   - ALCOHOL
2. HEAT TABLETS
3. WOOD

SUNBURN OINTMENT

MOSQUITOES
1. NETTING
2. REPELLENT

2 — EQUIPMENT TO FACILITATE RESCUE

SIGNALLING DEVICES
1. FLARES
2. MIRRORS
3. ELECTRONIC
4. "GIBSON GIRL"

PROPULSION ACCESSORIES
1. PADDLES, SAIL
2. SPECIAL FOOT GEAR CRAMPONS

3 — WATER

EXPENDABLE SOURCES
1. DESALTING KITS
2. CANNED WATER

NON-EXPENDABLE SOURCES
1. SOLAR STILLS
2. RAIN PAULIN

LOCAL SOURCES
1. LAKES
2. STREAMS
3. ICE AND SNOW

4 — INJURY OR SICKNESS

EXPOSURE
1. MOTION SICKNESS
2. FROST BITE
3. IMMERSION FOOT
4. SALT WATER DERMATITIS
5. SUNBURN
6. SNOW BLINDNESS

PHYSICAL DETERIORATION
1. DEHYDRATION
2. STARVATION
3. KETOSIS
4. ELECTROLYTE IMBALANCE
5. NITROGEN RETENTION

TRAUMATIC INJURIES
1. FRACTURES, BURNS
2. HEMORRHAGE, SHOCK
3. INFECTION
4. INSECTS, SHARKS

DETERIORATION IN MORALE
1. INITIATIVE
2. FORTITUDE
3. COURAGE
4. WILL TO LIVE

5 — NECESSITY FOR ENERGY EXPENDITURE

MAINTENANCE OF BODY HEAT

DEFENSE OR SELF-PROTECTION
1. SWIMMING
2. PADDLING
3. WALKING OUT

MAKING CAMP
1. COOKING
2. SHELTER
3. SIGNALLING
4. CHOPPING WOOD

6 — FOOD

SURVIVAL RATION

LOCAL SOURCES

shelter, clothing, sleeping bag, etc. Without them he could freeze to death before he could eat a fraction of the food. From the standpoint of the physiological economy of energy balance, it would be impractical if not impossible to supplant the advantages of sustained thermal insulation by the heat derived from the metabolic combustion of food. What is to be expected of a survival ration? Should it meet the minimum needs to barely permit the castaway to live in a basal state for an arbitrary period of time? Or, should it support a survivor so as to maintain a degree of strength to extricate himself from an hostile environment? Because of the numerous hazards which frequently confront the castaway, it would seem obligatory to provide a ration which does the latter, if he is to survive long enough to permit rescue.

The USAF needs a survival ration to be carried in aircraft at all times and to be used as an emergency source of food in case bailing out, crash landing or ditching becomes necessary. The ever-increasing range of modern aircraft, and the global concept of military strategy, make it essential that emergency rations meet survival requirements of the tropical, temperate and arctic areas, on land or sea. But these requirements may differ physiologically with the environment of the various geographical areas. A castaway may succumb to acute dehydration in the Tropics long before starving to death. He may freeze to death long before dehydration or starvation would take its toll in the Arctic. Thus, while water may be the critical factor to survival in the tropical environment, adequate protection against the cold is of fundamental importance in the Arctic. Food assumes a role of relative importance in so far as it may provide the initial or sustained energy for the maintenance of body heat and the performance of useful work. The body heat, capacity and strength for sustained work, and the maintenance of high morale as derived from food may be sufficient initially to prevent the castaway from freezing to death by enabling him to alter the immediate environment. If the survival period is thus prolonged, water may again become a limiting factor.

CAN AN ALL-PURPOSE RATION BE DESIGNED TO MEET PHYSIOLOGICAL NEEDS IN ALL CIRCUMSTANCES (ENVIRONMENTAL) OF SURVIVAL?

If military necessity requires that an all-purpose survival ration support a castaway on land or sea, and under the conditions of the tropical, temperate or arctic areas, then the design of such a ration would have to approach the minimum needs of the area where food is critical. This is justified if it can be done without imposing hazardous physiological stress upon the castaway in the areas where water is critical. The more food eaten, the more water required for its ingestion (8). If protein is present in the food, water requirements are increased in order to eliminate the nitrogenous end products (chiefly urea) in the urine.

It has been shown that 100 gms. of carbohydrate (400 calories) per day will prevent the development of ketosis when the caloric expenditure is barely above basal requirements; ie, approximately 2000 calories per day. This same amount of carbohydrate will decrease renal water requirement by reducing the production of organic acids and thus the solute load imposed upon the kidneys for elimination (5, 9). But, will this amount of carbohydrate prevent ketosis where a caloric expenditure of 4500 calories per day derives a greater proportion of fuel needs from stored body fat? Ketosis, according to the preponderance of recent evidence (10), presumably results from a disparity in ketone body production and utilization. Can utilization keep up with production when the latter is greatly increased because of heat loss to the environment while only 100 gms. of carbohydrate are ingested? What then is the minimum caloric intake and its nutrient composition which will prevent ketosis and physical inefficiency, arising from a marked caloric expenditure, as might occur under survival circumstances in the Arctic? Unfortunately, this information is lacking.

An all-purpose survival ration must be appraised in terms of its incidental cost to water balance, and not only upon its prevention of ketosis. The problem, then, which presents itself is — can a ration be designed which provides the following advantages to the survivor?

1. No increase in obligatory renal water requirement and an insignificant cost to expendable body water.

2. Prevents ketosis in the presence of a marked caloric expenditure.

3. Provides sufficient calories to maintain morale and sustain physical effectiveness.

4. High order of acceptability, storage stability and field utility.

A ration consisting of 100 gms. of carbohydrate fulfills the first of these requirements, but will it supply sufficient calories to comply with the other criteria? If more food is required, it would be desirable to incorporate protein and fat in the ration for the following reasons: (a) to enable the individual to willingly and easily ingest more calories each day over a period of seven to ten days; (b) to improve the palatability, flavor and consistency of the ration as well as to provide variety and thus enhance its acceptability; (c) protein will help spare body tissues of personnel so that they will be in the best possible physical condition when rescued and afford the wounded or sick a better chance of survival; (d) preliminary evidence indicates that the absence of protein in the diet is related to prolongation of arm-to-leg circulation time (11) which is an important consideration in the development of frostbite, trench foot and immersion foot; (e) protein and fat in the diet decrease the tendency to post-prandial hypoglycemia with its headache and decrease in morale; and (f) the inclusion of fat in the diet has been found to enhance physical performance (12) as well as to increase caloric density and thus reduce

space-weight requirement of the ration. Aside from these specific reasons, protein and fat improve the general nutritional adequacy of the ration.

SUMMARY OF THE PROBLEM

1. Should the castaway be provided with more than 100 gms. of carbohydrate per day (400 calories) to prevent ketosis and the physical inefficiency incidental to a marked caloric expenditure associated with the arctic environment?

2. If so, can a ration be designed to provide more than 400 calories derived from protein and fat as well as from carbohydrate, and yet not significantly increase obligatory renal water requirement or unfavorably influence body water expenditure?

3. Does consumption of such a ration for an arbitrary period of time (10 days) leave the castaway in a better condition to withstand subsequent starvation and water deprivation if rescue has not yet been accomplished?

Unfortunately, information is not available to answer all of these questions but the theoretical considerations, experimental design and methods described herein may serve to provide the necessary additional data with further studies.

IV. METHODS USED IN THE APPRAISAL OF SURVIVAL RATIONS

A. EXPERIMENTAL DESIGN

1. Control Phase
2. Experimental Phase
3. Recovery Phase

B. RATIONS

C. CLOTHING

D. LABORATORY METHODS

1. References
2. Freezing Point Depression of Urine

E. MEASUREMENTS AND CALCULATIONS

1. Body Weight
2. Nitrogen Balance
3. Caloric Expenditure
    a. Douglas Bag Method
    b. Heat Loss Method
4. Body Substance Catabolized
5. Components of the Water Exchange
6. Ration Acceptability

A. EXPERIMENTAL PLAN

Metabolic observations were made to study the influence of USAF emergency rations and a restricted water intake upon the nitrogen, water and energy exchanges in human subjects residing continuously for 10 days in a cold environment. Control studies included fasting for six days in the cold environment and subsistance upon emergency rations at ordinary room temperature.

The plan of study was divided into three consecutive periods: a standardization or control phase, an experimental phase and a recovery phase (Chart 2).

1. Control Phase

The control phase was a period of two weeks during which time "learning" was accomplished in the psychomotor performance and mental tests and a program of physical training was initiated. The latter consisted of graduated daily work periods on the treadmill, (variable speed and variable incline), rope skipping and striking the punching bag. The physical training was deemed necessary because of the limitation in type of activity to be permitted by eventual confinement in the cold chamber. During the second week of the control phase, the subjects subsisted on a standard regimen consisting of QM Combat Ration, Type E, providing approximately 3000 calories per day, and a constant adequate fluid intake (1500 cc per day). The purpose of this standard regimen was an attempt to bring about a relatively "stable metabolic state" with respect to nitrogen balance and urine volume. Although nitrogen equilibrium would have been desirable, it was not considered essential to attain that goal before proceeding to the experimental phase. The subjects went about their usual duties and kept accurate time activity data from which total caloric expenditure could be estimated by use of standard metabolic cost tables (corrected for deviations from the standard 70 Kg. man). The base-line studies conducted during this control phase included: the Mosenthal concentration and dilution kidney function tests; oral galactose tolerance and bromsulphalein retention liver function tests; daily 24 hour collections of urine for determinations of total nitrogen, chloride, total solutes, and routine urinalysis (sp. gr. pH, microscopic, albumin, acetone, acetoacetic acid, and sugar); fasting blood specimens were analyzed every other day for non-protein nitrogen, chloride, CO_2 content, sugar, hematocrit, hemoglobin, blood counts, (red, white, differential), plasma sp. gr. and protein concentration; basal metabolism, electrocardiogram, chest X-ray and complete physical examinations were performed to appraise the initial physical state and rule out obscure defects or illnesses (tuberculosis, cardiovascular disease and disturbances of basal metabolic rate); body weight was measured on a metabolic balance (accuracy 2 grams); and psychomotor performance was studied with a group of tests: S.A.M. Finger Dexterity Test

EXPERIMENTAL PLAN

REGIMEN	FLUIDS, 1500 cc. E-RATION, 3000 Cal.	FLUIDS, 800 cc. USAF EMERGENCY RATIONS,1000-2000 Cal.	FLUIDS, 1500 cc. E-RATION, 3000 Cal.
ENVIRONMENT	ROOM TEMPERATURE	CONTROLLED CHAMBER TEMPERATURES	ROOM TEMPERATURE
TESTS	PHYSICAL EXAMINATION KIDNEY FUNCTION TESTS EKG BMR CHEST X RAY URINE (24 Hr. COLLECTION) TOTAL N TOTAL Cl ΔT_f, TOTAL SOLUTES ROUTINE URINALYSIS BLOOD (FASTING) NPN Cl SUGAR PLASMA SP. GR., PROTEIN CO_2 CONTENT HEMATOCRIT RBC, WBC, HGB DIFFERENTIAL PSYCHOMOTOR PERFORMANCE TIME-ACTIVITY DATA BODY WEIGHT	DAILY PHYSICAL EXAMINATION RESPIRATORY EXCHANGE (DOUGLAS BAG) BODY TEMPERATURE (2 X SKIN TEMPERATURE (4 URINE (24 Hr. COLLECTION) TOTAL N TOTAL Cl ΔT_f, TOTAL SOLUTES ROUTINE URINALYSIS BLOOD (FASTING) NPN Cl SUGAR PLASMA SP. GR., PROTEIN CO_2 CONTENT HEMATOCRIT RBC, WBC, HGB STOOL—WATER CONTENT PSYCHOMOTOR PERFORMANCE TIME-ACTIVITY DATA BODY WEIGHT	FOLLOW UP PHYSICAL EXAM EKG BMR URINE (24 Hr. COLLECTION) TOTAL N TOTAL Cl ΔT_f, TOTAL SOLUTES ROUTINE URINALYSIS BLOOD (FASTING) NPN Cl SUGAR PLASMA SP. GR., PROTEIN CO_2 CONTENT HEMATOCRIT RBC, WBC, HGB STOOL—WATER CONTENT FOLLOW UP PSYCHOMOTOR TIME-ACTIVITY DATA BODY WEIGHT
DAYS	1 2 3 4 5 6 7	8 9 10 11 12 13 14 15 16 17	18 19 20 21 22
PHASE	CONTROL	EXPERIMENTAL	RECOVERY

(CM116A) simple reaction time, S.A.M. Single Dimension Pursuit Test (CM801E), code substitution and addition mental tests. Not all of the aforementioned studies were used in each experiment; those which consistently revealed no significant information or changes were gradually eliminated (see suggestions for further studies, section VII). The control phase was carried out at room temperature.

2. Experimental Phase

During the experimental phase of 6 to 10 days, the subjects suddenly entered the constant temperature, all-weather chamber (floor space 14 x 19 feet) in which were simulated the circumstances of survival following a crash landing, simulated with respect to environmental temperature and availability of emergency equipment, clothing, water and rations. With the realization that the effects of stress imposed by the cold environmental temperatures upon human performance and metabolism constitutes one of the greatest voids in information urgently needed by the Armed Forces (13), the emphasis in these studies was placed first upon the cold environment. The sequence of experiments as conducted and the environmental temperatures are listed below:

1. Test of USAF "developmental" emergency ration, No. 1; -29°C ±3°C, 9 days.

2. Test of USAF "developmental" emergency ration, No. 1; room temperatures, approximately +20°C ±1.5°C, subjects not confined to chamber because of their necessity to perform military duties, 10 days.

3. Fasting; -29°C ±1.5°C, 6 days.

4. Test of USAF "developmental" emergency ration, Nos. 2 and 3; +22°C ±2°C, 7 days.

5. Test of USAF "developmental" emergency ration, No. 2; Alaskan field trial, -25°C ±12°C, 10 days.

The wind velocity in the all-weather chamber was 3 to 5 m.p.h.; air movement was turbulent. The subjects subsisted on "developmental" USAF emergency rations and a daily free fluid intake of 800 cc. It has been estimated that the present type and quantity of water-providing equipment included in emergency sustenance kits will yield a minimum of 800 cc potable water/man/day for 10 days from the combined sources of canned water, solar stills, desalting kits and rain catchment devices (14, 15). Free fluid intake was kept constant at the level of 800 cc to be consistent with this probability as well as to insure minimum water intake (16). The ration was eaten in eight approximately equal portions; seven of them at two-hour intervals spaced throughout the day and the remaining portion was eaten as a snack during the night while in

the sleeping bag. This feeding pattern was used to take advantage of the information gained from the study of Keeton and Mitchell (17); that is, body temperature was found to be more easily maintained in the cold environment when the subjects ate small frequent meals in contrast to the conventional three.

The laboratory tests or procedures which appear below were selected in anticipation that they might yield critical information relative to the survival problems; namely, dehydration and electrolyte imbalance, ketosis, pre-renal nitrogen retention, deterioration in physical efficiency and morale, maintenance of body heat, and others. While the men were in the chamber, the following observations were made upon them:

1. State of hydration—as indicated by physical signs, hematocrit and hemoglobin concentration, urine volume, urine sp. gr. and osmolar concentration (freezing point depression), plasma sp. gr., and protein concentration, total urine nitrogen and solutes and the calculations of I.W., B.W., Wox, Min. Ur. W., Fe.W. and Min. W.I.

2. Acid-base balance—as reflected in urinary ketone bodies, urine pH, serum and urine chloride, serum CO_2 content.

3. Pre-renal nitrogen retention—as shown in the level of the blood non-protein nitrogen.

4. Body weight (daily in room temperature experiments; before and after, in the cold environment experiments)

5. Indices of physical state—evidence of renal damage in urine albumin and casts; development of anorexia, nausea or emesis; subjective estimate of physical strength and voluntary daily activity; Douglas bag collections of expired air were obtained daily during the various types of activity and analyzed with the Haldane apparatus for oxygen and CO_2 content; correlation of this information with time-activity data made possible a computation of total energy expenditure.

6. Psychomotor efficiency—daily measurements with the same group of tests used in the control phase.

7. Body temperature-measured with a rectal thermometer before getting out of the sleeping bag in the morning and again 30 minutes after getting into the bag to sleep in the evening (usually at 8:00 AM and 10:30 PM).

8. Skin temperatures--as registered with resistance thermometers taped to six representative areas of the body (palm, forearm, foot, calf, abdomen and back); recorded four times daily (usually at 8:30 AM, 11:00 AM, 2:30 PM and 9:00 PM).

9. Daily log of morale--as indicated by hunger, thirst, comfort (hot, cold, dry, wet), lassitude, irritability, cooperation, fortitude, etc.

10. Evidence of acclimatization--was sought in the white blood count and differential, BMR before and after the test phase, and the urine analysis for 11-OCS and 17-KS.

11. Ration acceptability--(see questionnaire).

3. Recovery phase

After their exit from the cold chamber, the men were weighed to determine cumulative body weight loss. The studies made during the control phase were repeated as the subjects subsisted on the standard regimen for a 3 to 5 day recovery period of observation.

B. RATIONS

The rations used in this study included QM Combat Ration, Type E, used during the control and recovery periods, and four emergency rations; namely, Parachute Emergency Ration which served as a control on current issue, and three "developmental" USAF emergency rations. These rations are illustrated in Figures 1-4; their components and nutrient analyses are summarized in Tables 1-5. Reference has already been made (see Summary and Conclusions) to the importance of the quality of protein to its efficiency of utilization and the level of urinary nitrogen. In the fabrication of the developmental test rations, an attempt was made to incorporate protein from highest quality sources. The sources of protein used in the test rations are indicated in Table 6.

C. CLOTHING

The experimental USAF clothing assembly worn by the subjects while in the cold environment is shown in Figure 5. It consisted of three layers: a modified cotten "sweat suit" for underwear, heavy wool knit trousers and waist length shirt, and an outer heavy flying suit (XB-67) of trousers and jacket made of double wool pile thermal cloth covered with nylon and a wolverine fur trimmed parka. The hand and foot gear are illustrated in Figure 6. The hands were protected by a rayon finger glove and a four piece mitten assembly (G-39). During the daytime the men wore light weight wool socks, a shearling inner boot with felt inner sole,

and an all-rubber mukluk type of outershell. The outer two parts of this assembly were taken off at night and a second pair of socks (heavy weight wool) and a wool pile "sleeping boot" were put on while in the sleeping bag. The complete clothing assembly worn by the men weighed 23 pounds and had a clo value of 4.09 (without air film) as determined on the copper man. This value was increased to 8.7 by the addition of a sleeping bag. The men slept in their clothing inside of an experimental USAF arctic sleeping bag (XB-3A) on top of an air mattress (Figure 7). Although advised to take off the heavy outer flying suit while in the sleeping bag, the subjects preferred not to, probably due to fear of the cold and lack of experience. An experimental USAF neon red, poncho-survival tent covered the sleeping bag to protect it from condensation "snow".

TABLE 1

QM, COMBAT RATION, TYPE E, MODIFIED[2]
(CQD 398A, 1946)

UNIT	COMPONENT	QUANTITY	WEIGHT gms	CHO gms	PRO gms	FAT gms	CALORIES
B-1	Sugar	1	47	47	0	0	188
	Cocoa Beverage	1	57	44	8	2	226
	Cereal, Premifed	1	57	38	8	7	247
	Coffee Prod., Sol	1	5	4	1	0	20
	Biscuits, Type V	2	20	14	2	3	91
	Jam, Canned	1	43	32	0	0	128
	TOTAL	7	229	179	19	12	900
B-2	Biscuits, Type V	2	20	14	2	3	91
	Fudge Disc	1	54	40	3	9	253
	Orange or Grape Beverage	1	7	7	0	0	28
	Butterscotch Cookie	1	23	16	1	5	113
	Jelly, Canned	1	43	32	0	0	128
	TOTAL	6	147	109	6	17	613
Fruit	Peaches or Pineapple	1	340	67	2	0	276
Meat	Variety of 10[2]	2	680	62	76	56	1056
Suppl. [3]	Starch-Jelly Candy	1	56	56	-	-	208
	TOTAL		1452	473	103	85	3053
	% - wt.			72	15	13	
	% - cal.			62	13	25	

1. Three meat units were used in the first three experiments (see page 3).

2. Chicken and vegetables, Hamburgers and Gravy, Pork and Rice, Ham and Lima Beans, Beef Stew, Pork and Beans, Meat and Beans, Franks and Beans, Meat and Noodles, Meat and Spaghetti.

3. Supplement added to ration to increase calorie value and CHO content.

FIGURE 1

QM. COMBAT RATION, TYPE E, MODIFIED

TABLE 2

PARACHUTE EMERGENCY RATION
(CQD 302A, 1945)

COMPONENT	QUANTITY	WEIGHT gms	CHO gms	PRO gms	FAT gms	CALORIES
Sweet Chocolate Bar	2	113	68	9	31	588
Charms Hard Candy	1	37	36	0	0	144
Cheese-cracker Bar	1	28	7	10	7	131
Bouillon Cubes	2	8	2	1	0	12
Sugar Cubes	2	11	11	0	0	44
Coffee Prod., Sol.	1	5	4	1	0	18
Gum (Chiclets)	3	12	9	0	0	36
TOTAL		214	137	21	38	973
% - wt.			70	11	19	
% - cal.			56	9	35	

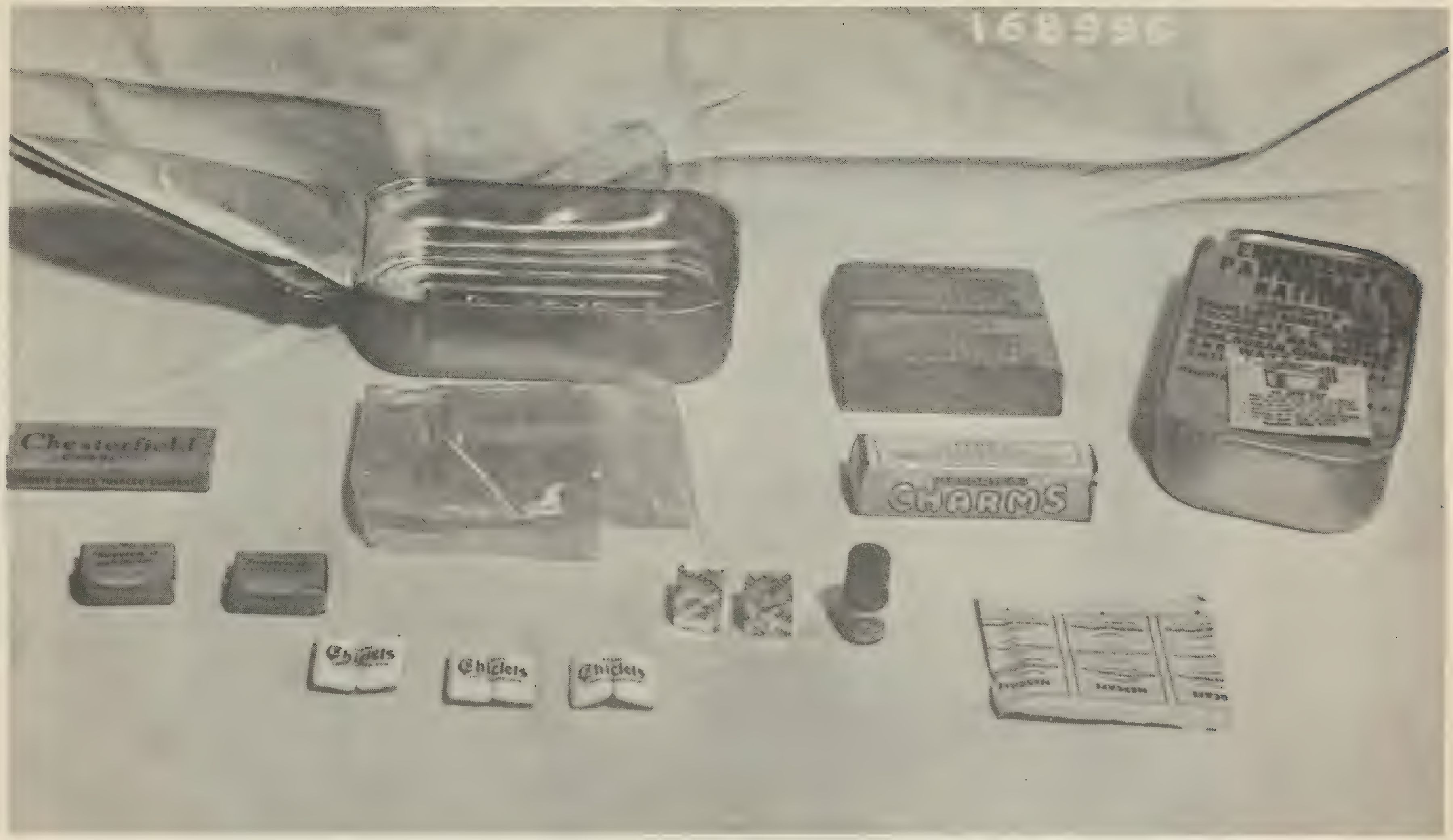

FIGURE 2

PARACHUTE EMERGENCY RATION

TABLE 3

USAF EMERGENCY RATION, DEVELOPMENTAL, NO. 1

COMPONENT	QUANTITY	WEIGHT gms	CHO gms	PRO gms	FAT gms	CALORIES
Egg Nog Bars	6	168	103.0	22.58	32.18	793
Cheese-cracker Bars	2	56	22.2	10.72	15.84	274
Chocolate-malt Bars	2	56	38.6	5.34	8.60	253
Starch-Jelly Bars	2	112	104.0	0.0	0.0	416
Bouillon Cubes	2	8	2.0	1.0	0.0	12
Sugar Cubes	4	22	22.0	0.0	0.0	88
Coffee Prod., Sol.	2	10	8.0	2.0	0.0	40
Gum (Chiclets)	6	24	18.0	0.0	0.0	72
TOTAL		456	317.8	41.6	56.6	1948
% - wt.			76.5	10.0	13.5	
% - cal.			65.3	8.5	26.2	

FIGURE 3

USAF EMERGENCY RATION, DEVELOPMENTAL, NO. 1

TABLE 4

USAF EMERGENCY RATION, DEVELOPMENTAL, NO. 2, MENU #1

COMPONENT	QUANTITY	WEIGHT gms	CHO gms	PRO gms	FAT gms	CALORIES
Oatmeal Bar (FD-1)	1	38.4	12.4	4.8	9.1	151
Cheese-cracker Bar (FD-2)	1	28.4	12.1	4.6	9.4	151
Chocolate Malt Bar (FD-3)	1	28.4	13.1	4.3	8.8	149
Vanilla Bar (FD-4)	1	28.4	12.3	4.8	9.1	151
Cocoanut Bar (FD-5)	1	28.4	12.1	4.8	9.3	151
Date-Apricot (FD-6)	1	28.4	15.0	3.2	4.4	112
Date-Apricot (FD-7)	1	28.4	15.4	3.2	4.4	114
Cheese Bar (FD-11)	1	28.4	14.9	6.2	4.8	128
Peanut-Cracker Bar (FD-12)	1	28.4	14.5	5.7	6.1	136
Peanut-Strawberry (FD-14)	1	28.4	18.0	4.0	4.4	128
Chocolate Bar (FD-16)	1	28.4	16.0	3.8	7.2	144
Starch Jelly (Charms)	2 1/2	142.0	130.0	0.0	0.0	520
Sugar Cubes	3	16.2	16.2	0.0	0.0	65
Gum (PK)	3	12.0	9.0	0.0	0.0	36
Bouillon Cube	1	4.0	1.0	0.5	0.0	6
Coffee Prod., Sol.	1	5.0	4.0	1.0	0.0	20
Tea Prod., Sol.	1	5.0	0.0	0.0	0.0	0
TOTAL		492	316	51	77	2162
% - wt.			72	11	17	
% - cal.			58	9	32	

FIGURE 4

USAF EMERGENCY RATION, DEVELOPMENTAL, NO. 2

TABLE 5

USAF EMERGENCY RATION, DEVELOPMENTAL, No. 3

COMPONENT	QUANTITY	WEIGHT	CHO gms	PRO gms	FAT gms	CALORIES
Cheese-cracker Bar (FD-2)	2	56.8	24.2	9.2	18.8	302
Vanilla Bar (FD-4)	1	28.4	12.3	4.8	9.1	151
Cocoanut Bar (FD-5)	2	56.8	24.2	9.6	18.6	302
Date-Apricot Bar (FD-7)	2	56.8	30.8	6.4	8.8	228
Egg White (Fermented)	2	10.0	0.0	10.0	0.0	40
TOTAL		209	92	40.0	55	1023
% - wt.			49	21	30	
% - cal.			36	16	48	

TABLE 6

SOURCES OF PROTEIN

IN DEVELOPMENTAL USAF EMERGENCY RATIONS

SOURCE OF PROTEIN	ER-1 %	ER-2 %	ER-3 %
Egg	49.1	55.7	77.5
Milk	24.0	11.3	2.4
Rice Flour		1.6	2.0
Peanut Butter		9.8	
Wheat Flour	24.9	13.9	10.1
Soya Flour		4.4	5.4
Oatmeal		0.2	
Dates-Apricots		2.1	
Chocolate	1.9	1.0	

EXPERIMENTAL USAF ARCTIC CLOTHING ASSEMBLY

FIGURE 6

HAND AND FOOT GEAR, EXPERIMENTAL

FIGURE 7

AIR MATTRESS, EXPERIMENTAL ARCTIC SLEEPING BAG, AND PONCHO-SURVIVAL TENT

FIGURE 8

SUBJECTS WALKING ON TREADMILL

D. LABORATORY METHODS

Serum separated from clotted venous blood drawn under oil was used for CO_2 content and chloride analyses, while heparinized whole blood was used for all other determinations. Blood samples were drawn every other day between 8:00 and 8:30 AM, preceding the first morning feeding. Urinary determinations were made daily on aliquots of 24-hour collections covering periods from 8:00 AM of one day to 8:00 AM of the next. The specimens were preserved with toluene, and in the refrigerator whenever possible.

All colorimetric laboratory methods were adapted for use in the Leitz photo-electric colorimeter. The methods employed were selected to permit interchangeable use of reagents with the Duboscq type of colorimeter and the photo-electric colorimeter to provide uniformity of methods in anticipation of electric power difficulties during the continuation of these studies in field trials.

The following laboratory methods were carried out:

1. Total urine nitrogen: Micro-Kjeldahl, Folin and Denis, J. Biol, Chem., 26: 473 (1916).

2. Urine and serum chlorides: Colorimetric; Sendroy, J. Biol. Chem., 130: 605 (1939).

3. Total urine solutes: freezing point depression; Beckmann, Zeit. phys, chem., 2: 653 (1888). Modified according to the recommendations of Schwimmer and Drekter as described below (Personal Communication).

4. Routine Urinalyses: sp. gr.--urinometer, corrected for temperature; pH - nitrazine paper (Squibb); sugar (qualitative) Bismuth Oxychloride spot test, Guidotti and Winer, Military Surgeon, 94: Feb., No. 2 (1944); acetone -- nitroferricyanide spot test (acetone Reagent - Galat) Stanley, Am. J. Med. Tech., 9: Jan, No. 1 (1943) or Lange's nitroprusside ring test; acetoacetic acid - Gerhardt's ferric chloride test; albumin--sulfosalicylic acid spot test or heat and nitric acid test; microscopic examination--Todd and Sanford, clinical Diagnosis by Laboratory Methods, 9th edition, W.B. Saunders Co., Phil., 1941.

5. Urine sugar (quantitative): micro-modification of the method of Benedict by Millard Smith, J. Lab. and Clin. Med., 7: 364 (1922).

6. Blood non-protein nitrogen: Folin and Wu; J. Biol. Chem.; 38: 81 (1919).

7. Blood sugar: Folin and Wu; J. Biol. Chem; 41: 367 (1920).

8. Serum Protein: colorimetric; Greenberg, J. Biol. Chem., 32: 545 (1924).

9. Plasma Sp. Gr. and Protein: falling drop method; Barbour and Hamilton, J. Biol. Chem., 69: 625 (1926).

10. Hematocrit: Wintrobe; J. Lab. and Clin. Med; 15: 287 (1939).

11. Hemoglobin: photo-colorimeter; Sheard and Sanford; Am. J. Clin. Path., 3: 412 (1933).

12. Red, white and differential blood counts: Todd and Sanford; Clinical Diagnosis by Laboratory Methods, 9th edition, W. B. Saunders Co., Phila. 1941.

13. Concentration--Dilution Kidney Function Tests: Mosenthal; idem.

14. Galactose Tolerance Test: idem.

15. Bromsulphalein Liver Function Test; photo-colorimeter; Rosenthal, J.A.M.A. 84: 1112 (1925; dose - 5 mgm Kg.

16. Basal Metabolic Rate: Benedict - Roth Apparatus.

17. Serum CO_2 Content: Peters and Van Slyke, Quantitative Clinical Chemistry, 1932, Vol. II, p. 95.

18. Respiratory Gases: Douglas bag or gasometer collection; idem, p. 283.

19. Electrocardiogram: General Electric Portable Cardiograph.

20. 11 - oxycorticosteroid - like substances: colorimetric; Talbot, J. Biol. Chem., 160: 535 (1945). 17 - Ketosteroids: Colorimetric; Fraser et al., J. Clin. Endocrin., 1: 234 (1941).

Technique of Freezing Point Determination

(Recommended by Schwimmer & Drekter)

The technique employed for determining the freezing point depression of urine (ΔT_f) was a modification of the method described

in "Experimental Physical Chemistry", Daniels, Mathews and Williams (1934), p. 53.

For doing large quantity freezing point depressions, two Dewar flasks were used. One flask, for pre-cooling the urine was kept at a temperature of approximately -5°C; the other, the freezing flask was maintained at -10°C. Temperatures were obtained by using an appropriate amount of salt in an ice slurry. A Beckman thermometer was adjusted so that at the temperature of melting ice the capillary stands about half way on the scale. The thermometer was fitted into a #7 rubber stopper to a depth which would permit the bulb to project about 1/4 inch from the bottom when placed in a freezing point tube. A stirrer was placed around the thermometer.

The freezing point tubes were rinsed twice with small amounts of the diluted urine and then were half filled with the diluted urine and placed in the pre-cooling bath. Pre-cooling them at a rate which would allow the determinations to be done before the urine freezes was determined by experience.

The Beckman thermometer was rinsed with the urine to be frozen and then inserted in the liquid. The quantity of urine remaining in the tube must be sufficient to completely cover the bulb of the thermometer. The freezing point tube plus the thermometer was then placed in the air jacket in the freezing flask and the actual freezing point determined.

The rate at which the tubes are inserted into the pre-cooling flask is determined by experience. However the urines must not be allowed to freeze prior to an actual reading since this will render the material useless for accurate readings.

Determinations were done on urine diluted 10 ml. to 100 ml. with double distilled water. The second distillation should be made from an all glass apparatus. This same water was used daily to determine the zero point of the Beckman thermometer. Duplicate determinations were run until at least two agree within 0.004°.

CALCULATIONS

(Freezing point urine - Freezing point water) X 10 =

actual depression of the freezing point.

$$\frac{\text{Actual Depr. Fr. Pt.}}{1.86} = \text{osmols/liter} \times \text{Volume, cc} =$$

total solutes, milliosmols

E. MEASUREMENTS AND CALCULATIONS

1. BODY WEIGHT

A metabolic balance with an accuracy of 2 grams was used to weigh the subjects every other morning before breakfast during the control

and recovery periods. An initial and final weight was obtained during the experimental phase of the cold environment studies to avoid the psychological hazard of coming out into a warm atmosphere and to avoid melting frost and ice particles on the clothing and thereby reducing the insulation provided. Daily body weights were recorded during the experimental phase of the room temperature studies in order to observe daily changes in insensible water and body water losses. Body weights were recorded in kilograms to the nearest 2 grams.

Nine different volunteer officer and enlisted personnel served as experimental subjects. Initial body weights ranged from 64.67 to 97.45 Kg.; surface areas from 1.78 to 2.22 sq. meters.

2. Nitrogen Balance ($N_B = N_I - N_U$)

Nitrogen balance is used in these studies to indicate the difference in nitrogen intake and urinary nitrogen output. Fecal nitrogen was not determined because (a) only a relatively small and a relatively constant amount of fecal nitrogen has been attributed to the diet (18); and (b) our interest was in the effect of dietary nitrogen upon minimum water requirement as influenced by the level of urinary nitrogen. For the latter reason also, no attempt was made to measure nitrogen loss through the skin, which may be considerably increased by physical activity (19).

Example: N_I = Ration Nitrogen Intake = 6.70 gms
N_U = Total Urine Nitrogen = 8.77 gms
N_B = Nitrogen Balance = 6.70 - 8.77 = -2.07 gms

3. Caloric Expenditure

Total caloric expenditure was estimated by two methods: a correlation of time-activity data with the metabolic cost of the various activities; and by the calculation of total heat loss through the clothing, evaporating insensible water loss from the lungs and skin, warming and humidifying inspired air and through external work performed.

a. Metabolic Cost of Various Activities.

Douglas bag collections of expired air were made during the various activities permitted within the confines of the all-weather chamber; such as, sleeping, lying quietly, sitting, standing, walking, treadmill (2.5 m.p.h. level), and playing catch. The test collection was made after a 5 to 15 minute period of wearing the rubber mouthpiece assembly and performing the activity to be measured in an attempt to arrive at a "steady metabolic state". The air in the Douglas bag was transferred to a spirometer to measure the volume under the existing conditions of temperature and barometric pressure, and to obtain a sample of the expired air for analysis of its O_2 and CO_2 content with the Haldane apparatus. The collection of expired air during a particular activity was timed with an electric stop clock

(graduated to 1/100 minute). In the room temperature studies, expired air was collected directly into the spirometer.

From the total pulmonary ventilation and the CO_2 and O_2 content of expired air compared with the inspired air, the consumption of O_2 and production of CO_2 are calculated. Energy expenditure is derived from these data by use of the following equations:

1. Pulmonary Ventilation (PMV)—is expressed as liters of air expired per minute, the wet gas volume being converted to standard temperature and pressure, 0°C. and 760 mm Hg. and dry, by use of a line chart (Laboratory Manual of Field Methods for Biochemical Assessment of Metabolic and Nutritional Condition, Harvard Fatigue Laboratory, 1945).

$$\text{PMV} = \frac{\text{Sp X Sp factor X STP Factor}}{\text{Time}} = \text{L/min.}$$

Sp = Spirometer reading, cms.
Sp Factor = Calibration factor of spirometer, L/cm
STP Factor = Conversion factor for wet gas volume to dry gas volume STP

2. "True Oxygen" represents the number of ml. of oxygen consumed for every 100 ml. of air expired. This value is obtained from a line chart relating the Haldane analyses of expired air for O_2 and CO_2 content to the RQ and "True Oxygen".

3. Respiratory Quotient (RQ) is the ratio of CO_2 expired divided by the O_2 consumed (CO_2 production/O_2 consumption). The RQ is derived from the line chart referred to above and is used in the calculation of the calorific value of a liter of oxygen (see 5 below).

4. Oxygen Consumption, 1/min = $O_2 = \frac{\text{PMV}}{100}$ X "True O_2"

5. Caloric Equivalent of one liter of oxygen (Cals/$1O_2$): was derived from the triangle of Michaelis (Du Bois, Basal Metabolism in Health and Disease, P.96, Lea and Febiger, Phil., 1936). The percentage of oxygen used in the metabolism of protein is obtained by dividing the nitrogen of the urine (N_u) voided during a given period (assumed to be constant for the 24 hour collection) by the total oxygen consumed (O_2) during the same period. The triangle relates the N_u/O_2 factor to the RQ and to the calories per liter of oxygen.

$$\text{Wt. Ratio, } N_u/O_2 = \frac{\text{Urine N, gms per 24 hrs.}}{O_2 \times 60 \times 24 \times 1.43} = \frac{\text{Urine N, gms}}{O_2 \times 2059}$$

O_2 = Oxygen consumption, 1/min.

1.43 = Wt. of 1 liter oxygen, gms

6. Energy Expenditure (calories/hour): The metabolic cost of a given task is expressed in calories per hour and computed from the following formula:

$$\text{Cals/Hr.} = O_2 \text{ consumption, l/min.} \times \text{Cals}/1O_2 \times 60$$

<u>Example</u> of Calculations to determine Metabolic Cost:

Activity -- walking on treadmill, 2.5 m.p.h., level

(a) Douglas Bag Calculations:

Collection started 10 hr. 0.00', ended 10 hr. 3.99' = 3.99 min.
Spirometer reading: start 6.00 cm, end 38.44 cm = 32.44 cm.
Spirometer Factor: 1 cm = 2.71 liters
Temperature = 22.0°C, Barometer = 733 mm. Hg.
STP Factor (from line chart) = 0.868

$$\text{PMV} = \frac{32.44 \times 2.71 \times 0.868}{3.99} = 19.1 \text{ l/min, STP, dry.}$$

(b) Haldane Analyses:

$\% CO_2 = 4.09$ $\% O_2 = 15.84$

(c) Calculation of oxygen consumption:

"True O_2" (from line chart) = 5.36

$$O_2 \text{ Consumption} = \frac{\text{PMV}}{100} \times \text{"True } O_2\text{"} = \frac{19.1}{100} \times 5.36 = 1.03 \text{ l/min.}$$

(d) Calculation of energy expenditure:

Urine N = 9.45 gms/24 hrs.

$$\frac{N_2}{O_2} = \frac{\text{Urine N}}{O_2 \times 2059} = \frac{9.45}{1.03 \times 2059} = 0.0045.$$

$\text{Cal}/1O_2$ (from triangle of Michaelis) = 4.74

$$\text{Cals/Hr.} = O_2 \times \text{Cal}/1O_2 \times 60$$
$$= 1.03 \times 4.74 \times 60 = 292 \text{ Cals/Hr.}$$

Correlation of the metabolic costs for the various activities with the time - activity data provided an estimate of total daily caloric expenditure. The amount of time spent (within 2 minutes) at the various activities for every half hour of each 24 hour period (8:00 AM to 8:00 AM) was recorded by an observer. The total time per 24 hours. for a particular activity; eg, walking on the treadmill, was multiplied by the metabolic cost to give the amount of calories expended on treadmill activity. The metabolic cost of those activities not actually measured with Douglas Bag collections (sleeping, eating) were obtained from data reported in the Field Manual of the Harvard Fatigue Laboratory.

Example: Application of this approach to an estimation of total caloric expenditure is illustrated in Table 7 and the calculation which follows:

Activity	Time, Hrs.	Cals/Hr.	Total Calories
Sleep	5.75	60	345
Lying	6.17	70	432
Eating	0.42	90	38
Reading	3.58	75	269
Writing	2.33	100	233
Walking	5.25	150	788
Treadmill	0.50	210	105

Total caloric expenditure in 24 hrs. = 2210

b. Calculation of Total Heat Loss:

Total Caloric expenditure is equal to the metabolic heat production (M) of the body plus the energy expended in the performance of external work (W). A work efficiency of 5 per cen' 's assumed for the 24-hour period and this energy expended in the performance of external work is defined as 5 per cent of the total caloric expenditure. Metabolic heat production can be estimated by use of the following equations (20, 21):

$$M = H_{cl} + E_l + E_s + A - D$$

The heat debt (D) has been defined as the loss of stored heat through cooling of the body tissues. Rectal temperatures never fell below 98°F. and skin temperatures remained within the range for comfort. It was therefore, assumed for the purpose of these calculations that the heat debt was negligible.

1. H_{cl} = Heat loss through clothing = $\dfrac{3.09\ (T_s - T_o)}{I_{cl} + I_A} \times SA \times Hrs$

T_s = Average weighted skin temperature.
T_o = Operative environmental temperature.
SA = Surface area, sq. meters.
Hrs = Time in hours.
I_{cl} = Clo value of clothing assembly.
I_A = Clo value of the air at the wind velocity present during the test.

"Skin temperatures" as registered with resistance thermometers taped to six representative areas of the body were recorded four times daily (usually at 8:30 AM, 11:00 AM, 2:30 PM and 9:00 PM). The average skin temperature was calculated by dividing the body surface into five areas (Table 8): feet; lower legs; upper legs, trunk and upper arms; head, neck and lower arms; and hands. Each area was assigned a weighting

TABLE 7

TIME-ACTIVITY DATA

Name JR
Date 1/21/48
Day of Test 6

Time	Sleeping	Lying	Sitting	Eating	Cards	Reading or Conversation	Writing	Walking	Treadmill	Other Activities
0800-0830								30		
0830-0900							5	25		
0900-0930				5			5	20		
0930-1000						5	25			
1000-1030								30		
1030-1100							10	20		
1100-1130				5			25			
1130-1200							20		10	
1200-1230							20	5	5	
1230-1300						20	10			
1300-1330						15		15		
1330-1400						15	5	10		
1400-1430						10		20		
1430-1500						10		20		
1500-1530				5		20		5		
1530-1600						5		25		
1600-1630							15		15	
1630-1700		30								

TABLE 7 (Cont'd)

Time	Sleeping	Lying	Sitting	Eating	Cards	Reading or Conversation	Writing	Walking	Treadmill	Other Activities
1700-1730	15	15								
1730-1800	30									
1800-1830	30									
1830-1900	30									
1900-1930		10		10		5		5		
1930-2000						25		5		
2000-2030						25		5		
2030-2100						30				
2100-2130						15		15		
2130-2200						15		15		
2200-2230								30		
2230-2300		15						15		
2300-2330		30								
2330-2400		30								
0000-0600	120	240								
0600-0630	30									
0630-0700	30									
0700-0730	30									
0730-0800	30									
Total Hrs.	5.75	6.17		0.42		3.58	2.33	5.25	0.50	

coefficient according to its surface area, and the five weighted average regional skin temperatures were added to give the average skin temperature.

TABLE 8

WEIGHTING COEFFICIENTS FOR REGIONAL SKIN TEMPERATURES

(Based Upon Surface Area)

Body Area	Weighting Coeff.	Location of Thermometer
Head, neck Lower Arms	0.116	Left forearm
Hands	0.070	Left palm
Upper Legs Trunk, upper Arms	0.516	Abdomen, scapula
Lower Legs	0.204	Left calf
Feet	0.095	Left foot (arch)

2. E_l = Heat loss through vaporization of moisture from the lungs.
   E_l = (0.0353g H_2O) x (0.58 Cal., heat of vapor) x PMV x 1.18
   E_l = 0.0242 x PMV

   PMV = Pulmonary ventilation in liters per 24 hours
   0.0353 = amount of water/liter of expired air saturated at 33°C.
   0.58 = heat of vaporization of water, Cal./gm.
   1.18 = conversion factor, volume of ventilation STP dry to 33°C. wet.

3. E_s = Heat lost through vaporization of moisture from the skin
   E_s = (IW x 0.58) - E_L

   IW = insensible water loss from both skin and lungs (see water balance calculations)

4. A = Heat lost through warming inspired air

   A = (T.exp. air - T. insp. air) x 0.00031 x PMV
   0.00031 = (1.293g./liter, sp. gr. of air) x (0.00024 Cal/g., sp. heat of air)

5. W = Energy expended in the performance of external work

$$= \frac{H_{Cl} + E_s + E_l + A}{19} = \text{5 per cent of total caloric expenditure}$$

6. Total Caloric Expenditure = M + W or

$$= H_{Cl} + E_s + E_l + A + W$$

Example: Calculation of total caloric expenditure from consideration of the various channels of heat loss:

Operative environmental temperature = T_o = -20°F.
Weighted average "skin temperatures" = T_s = +84°F.
Surface area of subject = 1.78 M^2
Time out of sleeping bag = 8.69 hours
Time spent in sleeping bag = 15.31 hours

Clo value of clothing = I_{Cl} (O) = 4.09
Clo value of clothing and sleeping bag = I_{Cl} (I) = 8.70
Clo value of air = I_a = 0.70
Pulmonary ventilation = 11, 586 liters/24 hrs.

IW = 945 C.C.
Temperature of expired air = T_{ea} = assumed to be + 33°C.
Temperature of inspired air = T_{ia} = -29°C.

$$H_{Cl(O)} = \frac{3.09\ (84 + 20)}{4.09 + 0.7} \times 1.78 \times 8.69 = 1035$$

$$H_{Cl(I)} = \frac{3.09\ (85 + 20)}{8.7 + 0.7} \times 1.78 \times 15.31 = 883$$

$$E_l = 0.0242 \times PMV = 0.0242 \times 11{,}586 = 280$$

$$E_s = (IW \times 0.58) - E_l$$
$$= (945 \times 0.58) - 280 = 268$$

$$A = (T_{ea} - T_{ia}) \times 0.00031 \times PMV$$
$$= (33 + 29) \times 0.00031 \times 11{,}586 = 190$$

$$W = \frac{H_{cl} + E_l + E_s + A}{19}$$

$$W = \frac{1035 + 883 + 280 + 268 + 190}{19} = 140$$

Total caloric expenditure = 2796

4. Body Substance Catabolized

The amount of body substance catabolized daily was calculated from the total urine nitrogen, total caloric expenditure, weighted average respiratory quotient (RQ), and the weighted average caloric equivalent of a liter of oxygen. The average RQ for each type of activity was

assigned a weighting coefficient according to the amount of time spent in that activity to derive the weighted average RQ. The same procedure was followed to calculate the weighted average caloric equivalent of a liter of oxygen. It is estimated from the analytical figures of the average protein (22) that 1 gram of urinary nitrogen represents the metabolism of 6.25 g. of protein, the absorption of 5.91 liters of oxygen, the production of 4.76 liters of carbon dioxide, and the liberation of 26.51 calories. The application of these constants to the calculation of the body substance catabolized per day follows:

<u>Example:</u> Subject: H.B., Fasting -29°C.

Total urine nitrogen = 9.79 gms
Total caloric expenditure = 2800 calories
Weighted average RQ = 0.76
Weighted average Cal/1.O_2 = 4.73

$$\text{Total } O_2 \text{ absorbed} = \frac{2800}{4.73} = 592 \text{ liters}$$

Total CO_2 produced = 392 x 0.76 = 450 liters

9.79 gms urinary nitrogen represents:
9.79 x 6.25 = 61.2 gms protein metabolized
9.79 x 5.91 = 57.8 liters of O_2 absorbed
9.79 x 4.76 = 46.6 liters of CO_2 produced

Total CO_2 (or O_2) - protein CO_2 (or O_2) = non-protein CO_2 (or O_2).

450 liters CO_2 - 46.6 liters CO_2 = 403 liters CO_2
592 liters O_2 - 61.2 liters O_2 = 534 liters O_2

$$\frac{403 \text{ liters } CO_2}{534 \text{ liters } O_2} = 0.755 \text{ (Non-Protein RQ)}$$

When the non-protein RQ is 0.755, Zuntz and Schumberg's Table (23) (modified by Lusk) indicates that 1 liter of O_2 represents the liberation of 4.745 calories, and 17.4 per cent of the non-protein heat is derived from carbohydrate and 82.6 per cent from fat.

534 liters O_2 x 4.745 = 2534 Cal. (Non-Protein)
17.4% of 2534 = 441 Cal. from CHO
82.6% of 2534 = 2093 Cal. from FAT

The weight of body substance catabolized is calculated from the urinary nitrogen and the amount of heat (calories) derived from carbohydrate and fat using the constants for the heat of combustion of foodstuff in animals.

9.79 gms urinary N x 6.25 = 61.2 gms protein
441 Cal. from CHO ÷ 4.1 = 107.5 gms carbohydrate
2093 Cal. from FAT ÷ 9.3 = 225.0 gms fat
Total body substance* catabolized = 393.7 gms

*Not including body water or electrohytes: The C, P and F content of the diet are subtracted from these values when a ration is fed.

5. Components of the Water Exchange

A discussion of the considerations in water balance which have been used in these studies appears in the publications of Gamble (8, 9, 16), Newburgh (24) and Peters (25). The series of equations used to calculate the various components of the water exchange follow:

a. Insensible Water Loss (IW):

The term "insensible water loss" is used here to include not only the insensible evaporation of moisture from the skin and lungs but also the visible sweat. Perhaps more appropriate terminology would be "extra renal water loss". The insensible water loss equals the insensible weight loss (IL) of the body minus the weight of carbon dioxide produced in excess of oxygen absorbed:

$$IW = IL - WT\ (CO_2 - O_2)$$

Insensible weight loss was taken as the change in body weight plus the weight of the ingesta minus the weight of the excreta, thus:

$$IW = (Wt.\ loss + Wt.\ WI + Wt.\ FI) - (Wt.\ Ur + Wt.\ Fe + Wt.\ (CO_2 - O_2)$$

Wt. loss = Initial - final body weight, gms
Wt. WI = Weight of water intake, gms
Wt. FI = Weight of food (ration) intake, gms
Wt. U_r = Weight of urine (Ur. vol., cc x sp. gr.)
Wt. Fe = Weight of feces
Wt $(CO_2 - O_2)$ = (1.96 x liters CO_2) - (1.43 x liters O_2)

b. Urine Water (Ur.W);

Ur.W = Wt. Ur.- Wt. Ur. Solids
Wt. Ur. = Ur. Vol, cc x Sp. Gr.
Wt. Ur. solids = (Sp. Gr. - 1) x 2.6 x Ur. Vol., cc.
Ur.W = (Ur. Vol. x Sp. Gr.) - (Sp. Gr. -1) x 2.6 x Ur. Vol.)

c. Minimum Urine Water (Min. Ur.W.):

The definition of Min. Ur. W. requirement was approached from a measurement of the freezing point depression of the urine (ΔT_f). Estimation of the minimum physiological expenditure of water by the kidneys requires definition of the maximum ability of the kidney to concentrate solutes in urine and the daily quantity of solutes claiming removal from blood plasma. Gamble (9) observed an average maximum osmolar concentration of 1.40 for human subjects fasting and thirsting, or taking a greatly limited water intake (Fig. 9). Minimum urine water requirement was estimated from the freezing point depression and the 24 hour urine volume as follows:

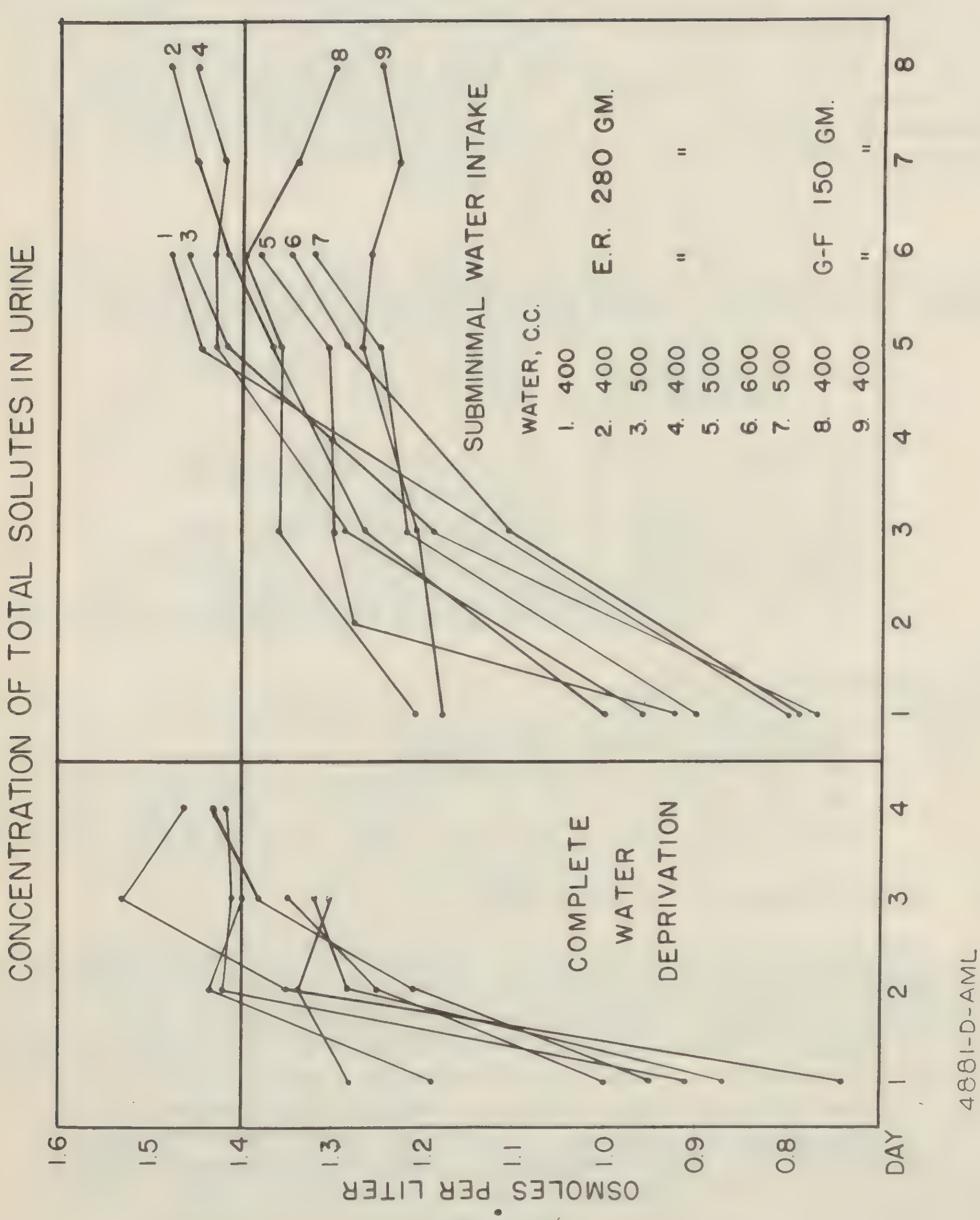
CONCENTRATION OF TOTAL SOLUTES IN URINE
OSMOLES PER LITER
DAY
COMPLETE WATER DEPRIVATION
SUBMINIMAL WATER INTAKE
WATER, C.C.
1. 400
2. 400 E.R. 280 GM.
3. 500
4. 400 " "
5. 500
6. 600
7. 500
8. 400 G-F 150 GM.
9. 400 " "
4881-D-AML

FIGURE 9

1. $\frac{\Delta T_f \text{ Urine}}{1.86}$ = osmolar concentration of solutes, osmoles/liter

   1.86 = molality freezing point lowering constant

2. Urine vol., ml. x osmolar conc., osM/l = total solutes, milliosmoles

3. $\frac{\text{Total solutes, m-osM}}{1.40}$ = Minimum urine volume, ml

4. (Min. Ur. Vol., ml. x 1.035) - Wt. Ur. Solids = minimum urine water

   1.035 = average maximum sp. gr. of urine having a concentration of 1.40 osM/l.

d. Water of Oxidation (W_{ox}):

Water produced in the combustion of foodstuffs, whether these are derived from exogenous sources or from tissues of the body, is water of oxidation. The amount of carbohydrate, protein and fat burned from both exogenous and endogenous sources (total metabolic mixture) has been derived in the calculation of the "body substance catabolized". Water of oxidation from the total metabolic mixture was computed by using the usually employed factors: gms. carbohydrate x 0.600, gms. fat x 1.071 and gms protein x 0.396.

e. Body Water Loss (BW):

The expenditure of preformed body water was estimated from the values found for the other components of water exchange:

$$BW = (IW + Ur.W + Fe\ W) - (WI + W_{ox})$$

Fe W = fecal water, determined by desiccation of stools
WI = free fluid intake + preformed water in the ration

Partition of BW: The loss of intra-cellular water (ICW) may be obtained in the presence of an ample water intake by measuring the loss of an intra-cellular fluid component (nitrogen) in the urine. Assuming the normal ratio of protein to water in cell fluid as 1:3.2, removal of ICW accompanying oxidation of body protein will be expressed as follows:

$$ICW = \text{Nitrogen balance, gms} \times 6.25 \times 3.2$$

The change in extra-cellular fluid (ECW) is obtained from measurements of serum chloride concentration (Cl) at the beginning and end of an interval over which the gain or loss of chloride by the body is determined. In the application of Darrow's method of calculating changes in ECW, the extra-cellular fluid volume is defined as 20 per cent of body weight and concentration of chloride in ECW is taken as the serum (Cl) multiplied by the factor 1.11.

Body weight x 0.20 = Initial ECW

Initial ECW x (Initial Serum (Cl) x 1.11) = Initial total Cl in ECW

Initial Cl in ECW + Cl Balance = Final Total Cl in ECW

Final Total Cl in ECW ÷ (Final Serum (Cl) x 1.11) = Final ECW

f. Minimum Water Intake (Min. W. I.):

The estimation of minimum water intake was derived from the values found for the other components of the water exchange as indicated by the diagram, Figure 18.

$$\text{Min. W.I.} = (\text{IW} + \text{Min. Ur. W} + \text{Fe W}) - (W_{ox} + \text{BW})$$

It is apparent that this equation is applicable only when the kidney is concentrating to 1.40 osM/l, or less, when it may be assumed that body water is not being withdrawn beyond the physiologically available quantity (see section on Discussion).

Example: of calculations to estimate Min. W.I.:

Data: Initial body weight = 58,008 gms
Final body weight = 57,396 gms
Urine volume, 24 hrs. = 490 cc.
Urine Sp. Gr. = 1.032
Food Intake = 208 gms, Water intake = 800 cc.
Respiratory exchange: 451 liters O_2
352 liters CO_2

Weight of feces = 0 gms; water content = 0
Metabolic mixture = 112 gms CHO
58 gms PRO
150 gms FAT

ΔT_f Urine = 2.30°C.

1. Insensible water loss:

$$\text{IW} = (\text{Wt. loss} + \text{Wt. W.I.} + \text{Wt. FI}) - (\text{Wt.Ur} + \text{Wt.Fe} + \text{Wt}\ (CO_2 - O_2))$$

$$\text{Wt. Ur.} = 490 \times 1.032 = 506$$

$$\text{Wt}\ (CO_2 - O_2) = (352 \times 1.96) - 451 \times 1.43) = 45$$

$$\text{IW} = (612 + 800 + 208) - (506 + 0 + 45) = 1069\ \text{cc.}$$

2. Urine Water:

$$\text{Ur. W.} = \text{Wt. Ur} - \text{Wt. Ur. Solids}$$

$$\text{Ur. Solids} = (1.032 - 1) \times 2.6 \times 490 = 41$$

$$\text{Ur. W.} = 506 - 41 = 465\ \text{cc.}$$

3. Minimum Urine Water:

$$\frac{\Delta T_f \text{ Urine}}{1.86} = \frac{2.30}{1.86} = 1.34 \text{ osM/l., osmolar conc.}$$

$$490 \times 1.34 = 657 \text{ m-osM, total solutes}$$

$$\frac{657}{140} = 469 \text{ cc. Min. Ur. Volume}$$

$$(469 \times 1.035) - 41 = 444 \text{ cc. Min. Ur. W.}$$

4. Water of Oxidation:

$$W_{ox} = (112 \times 0.600) + (58 \times 0.396) + (150 \times 1.071) = 250 \text{ cc.}$$

5. Body Water Loss:

$$\begin{aligned} BW &= (IW + Ur.W + Fe\ W) - (WI + W_{ox}) \\ &= (1069 + 465 + 0) - (818 + 250) = 466 \text{ cc.} \end{aligned}$$

6. Minimum Water Intake:

$$\begin{aligned} Min.W.I. &= (IW + Min.\ Ur.W. + Fe\ W) - (W_{ox} + BW) \\ &= (1069 + 444 + 0) - (250 + 466) = 797 \text{ cc.} \end{aligned}$$

6. Ration Acceptability

Acceptability of the various components of the emergency rations was appraised by a questionnaire, Chart 3. This questionnaire was devised especially for use in controlled experiments by Dr. W. Franklin Dove, Chief, Food Acceptance Branch, Quartermaster Food and Container Institute. A questionnaire was filled out daily by each subject, expressing his reactions to all of the components of the ration each time they were eaten. The completed questionnaires were submitted to Dr. Dove for statistical analysis and interpretation to be used in the formulation of new ration components by the Quartermaster Food and Container Institute. The directions for use of the questionnaire follow:

"This form has been designed especially for use in the laboratory or in the test chamber by subjects qualified and trained to record their personal reactions and observations. All records should represent the spontaneous reactions of the individual subject, uninfluenced by discussion with others. A period prior to the test should be allotted to acquainting observers and subjects with all items of the ration, all conditions of the test, and all types of records to be secured.

"This record form has been designed especially for use in the analysis of acceptability of the USAF emergency ration where the ration bars are identified only by a code letter and number. The same forms may, however, be used in the control ration tests, i.e. on Parachute Emergency Ration, the E or C2 Ration, or even for the group on starvation, when the record of water consumption and food craving is recorded to serve as a reference of comparisons for all other tests.

SURVIVAL RATION ACCEPTANCE RECORD
(For Laboratory Use By Trained Observers)
FOOD ACCEPTANCE RESEARCH BRANCH
QUARTERMASTER FOOD AND CONTAINER INSTITUTE
January, 1948

Name ______________________

Date ______________________

Day of Test ______________

TIME OF DAY	RATION BAR CODE NO. OR ITEM NAME	NOT TRIED WHY?	AMOUNT OF BAR EATEN [ ] ¼ [ ] ½ [ ] ¾ [ ] ALL	HOW EATEN? (H) HOT (B) BODY TEMP. (C) COLD (F) FROZEN	CHECK DEGREE OF LIKE OR DISLIKE AND WRITE REASONS AND CONDITIONS								HOW MANY OF EACH BAR EATEN WOULD YOU DESIRE PER DAY
					LIKE				DISLIKE				
					VERY MARKEDLY	MARKEDLY	MODERATELY	SLIGHTLY	SLIGHTLY	MODERATELY	MARKEDLY	VERY MARKEDLY	
1.		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
2		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
3		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
4		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
5		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
6		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
7		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
8		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
9		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
10		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	

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CONTINUE ON REVERSE SIDE

(OVER)

SURVIVAL RATION ACCEPTANCE RECORD

(For Laboratory Use By Trained Observers)
FOOD ACCEPTANCE RESEARCH BRANCH
QUARTERMASTER FOOD AND CONTAINER INSTITUTE
January, 1948

Name ______________________

Date ______________________

Day of Test ______________

TIME OF DAY	RATION BAR CODE NO. OR ITEM NAME	NOT TRIED WHY?	AMOUNT OF BAR EATEN [ ] $\frac{1}{4}$ [ ] $\frac{1}{2}$ [ ] $\frac{3}{4}$ [ ] ALL	HOW EATEN? (H) HOT (B) BODY TEMP. (C) COLD (F) FROZEN	CHECK DEGREE OF LIKE OR DISLIKE AND WRITE REASONS AND CONDITIONS								HOW MANY OF EACH BAR EATEN WOULD YOU DESIRE PER DAY
					LIKE				DISLIKE				
					VERY MARKEDLY	MARKEDLY	MODERATELY	SLIGHTLY	SLIGHTLY	MODERATELY	MARKEDLY	VERY MARKEDLY	
1.		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
2		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
3		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
4		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
5		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
6		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
7		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
8		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
9		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	
10		[ ]			[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	

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CONTINUE ON REVERSE SIDE

(OVER)

The same questionnaire form may be used for a pre and post inventory of attitudes toward items in other rations only when the different food items are well known, or are recognizable by appropriate labels.

"Two record cards are required for each emergency ration of nineteen different items. An explanation of the terminology used in the questionnaire follows:

"Time of Day (A record of the time of day when food or liquid is taken):

(1) A time schedule has been established for some of the tests, especially those under controlled conditions in the chamber tests at Wright Field. (2) The subjects will be required to consume all of the bars and all of the liquid of the ration within the twenty-four hours. (3) A record of time of day when both food and drink are taken is important. According to the columns allowed for the nineteen items in the ration, the record for water consumption -- if at some other time that at meal time -- should also include a record of the time of day.

TIME SCHEDULE FOR FOOD AND LIQUID CONSUMPTION

(For Controlled Laboratory and Field Tests)

Time	Item Consumed	Water Consumption
8:00 A.M.	2 Bars, coffee + 1 1/2 cubes sugar	(200 cc. as coffee)
10:00 A.M.	1 Bar Gum and 1/2 Charm	100 cc. water
12:00 Noon	1 Bar, Bouillon, 1 Charm	(200 cc. as soup)
2:00 P.M.	2 Bars and Gum	
4:00 P.M.	2 Bars	100 cc. water
6:00 P.M.	1 Bar, tea + 1 1/2 cubes sugar, 1 Charm	(200 cc. as tea)
8:00 P.M.	2 Bars and Gum	

"Ration Bar Code Number or Item Name:

For acceptance tests on items such as bars of similar nutritive value but made up of different ingredients and differing in flavor, texture, etc., a blind test is indicated. A blind test is carried out by means of codes. The codes used in this experiment identify bar content, date of manufacture (fresh or old), and menu combination. The test subject should not know the code. The key to the code is supplied at the end of the experiment. In the experiments using E-rations or identifiable items, this space may be used for the name of the food.

"Not Tried, Why?

Since some of the tests allow for freedom in acceptance of any one or more bars or items, the record of Not Tried separates out those items which were not classified for acceptability. A record of why the item was not tried reveals the difference between lack of appetite or lack of hunger on the part of the subject as against those reasons which might be attributed to defects in the bar or item.

"How Eaten? H = Hot; B = Body Temperature; C = Cold; F = Frozen.

Acceptability of each item is affected by the temperature at which it must be eaten. A frozen item may be too brittle, a warm item too gummy.

"If the ration is distributed each morning from a frozen stock pile, the subjects will be liable to make a record for the first two bars taken at 8:00 A.M. as of a frozen bar, while those taken later in the day and kept near the body would be as of a warmed-up bar. In the controlled chamber tests, therefore, the bars will be distributed at meal time only, and kept frozen in the interim.

"The record form allows for all of these contingencies, R - Room Temperature if temperature of 70° is indicated. Summer room temperature or tropical room temperature might be labelled "W" for warm or "H" for hot.

"Amount of Bar Eaten:

A record of the amount of each bar eaten (or refused) represents a measure of acceptance rate and optimum bar size and is not necessarily correlated with intensity or acceptability rating. This record will be secured only in those tests where freedom is permitted.

"Degree of Like or Dislike with Reasons and Conditions:

By means of a check mark the record of degree of like or dislike may be simply recorded for each bar as consumed. One syllable words or a line statement will provide succinct reasons for the opinion. These statements are important for reformulation (after the statements have been evaluated statistically).

"How Many of Each Bar Eaten Would You Desire Per Day:

As the bar or item is eaten, the subject subjectively wishes for more (or less) than the amount supplied. He may wish (at the time) that all eleven bars were of that particular kind. If so, he records eleven bars. The frequency with which each bar is desired and the frequency in which they appear differently in each menu provides the data for revising or justifying the menus as set up. This data also provides information on saturation rate and rate of development and nature of monotony.

"Describe Other Defects or Advantages:

"Other defects" may be those attributed to coating, to package, to temperature, humidity, insects, dust, lack of water, etc which though not a part of the food, come to affect acceptability or influence consumption of the food. These gripes may be rated in degrees of severity, with word statements to describe them.

"After-Effects: What and When, Good and Bad:

The record up to this point draws attention to immediate responses as the food is eaten. Continual acceptance is also influenced by after-effects, both positive and negative. Some foods seem to be conducive to sleep, others not, etc. After-effects should, therefore, be noted whenever they appear in consciousness. The record should include time of day together with word description and cause suggested.

"What Foods Do You Crave?:

These records should include time of day and should be specific as to food craved regardless of its supposed absurdity.

"Suggested Improvements:

Space allowed for both general and specific suggestions."

V. RESULTS

A. FASTING EXPERIMENTS — COLD ENVIRONMENT STUDY

B. EXPERIMENTS WITH USAF EMERGENCY RATION, DEVELOPMENTAL NO. 1

1. Cold Environment Study
2. Room Temperature Study

C. EXPERIMENTS WITH USAF EMERGENCY RATION, DEVELOPMENTAL NO. 2

1. Room Temperature Study
2. Alaskan Field Trial

D. PRELIMINARY STUDIES

1. USAF Emergency Ration, Developmental No. 3
2. Technique of the Freezing Point Determination on Urine

RESULTS

A. FASTING EXPERIMENTS — COLD ENVIRONMENT STUDY

The data obtained from two subjects during a fast of 6 days duration with "ample" water intake while residing continuously in a cold environment (-29°C ± 0.5°C) are summarized in Tables 9-17. Although this was not the first experiment conducted in the chronological sequence, the data are presented first to provide a basis for subsequent measurement of changes produced by consumption of the test rations in the presence of water deprivation. Unless otherwise specified, the tabulated data presents average values for the fourth through the sixth days of the experimental phase to permit comparison of results with those obtained by Gamble (9).

The changes in clinical laboratory data obtained during fasting in the cold environment are given in Tables 9 and 10. The average cumulative loss of body weight represented 7.55 per cent. The gross increased difference between WI and Ur. Vol. during the first 3 days of recovery imply a physiological need for water. However, in the absence of measurements of the IW during this period, quantitative proof for this implication is lacking. The difference referred to may result from salt retention during the recovery period, indicated by the relatively low urine chloride. The marked reduction in urine chloride while fasting reflects the decrease in chloride intake (approx. 1.0 gm. as sodium chloride in the tap water provided) and reflects the attempt on the part of the body to conserve salt. The average (6 day) value found for urine nitrogen, 10.12 gms., represents the daily catabolism of approximately 63 gms. of body protein.

Benedict observed a low N output in the urine (7.10 gms) on the first day of Levanzin's fast (19) with a higher nitrogen excretion on the subsequent two days (9.57 gms). This he attributed to the protecting action of the body storage of glycogen. The average daily urinary nitrogen for the fasting subjects here reported was slightly higher on the first day (12.09 gms.) than on the subsequent two days (11.28 gms.). The explanation of this difference is probably provided by a "lag effect" from the high nitrogen intake during the control phase.

The slight reduction in the CO_2 content of the serum reflects the stress of starvation acidosis, but also indicates a compensated state exists; i.e., the kidneys are capable of elaborating ammonia to conserve fixed base and of eliminating acid metabolites. The excretion of ketone bodies in the urine increased rapidly after the first day of fasting, which is attributed to a depletion of the glycogen stores (anti-ketogenic).

KETONE BODIES IN THE URINE

Subject		HB		DA	
Phase	Day	Acetone	Acetoacetic Ac.	Acetone	Acetoacetic Ac.
Control	7	0	0	0	0
Fasting	1	Trace	0	++	0
	2	+++	0	++++	+
	3	++++	+	++++	+
	4	++++	+	++++	+
	5	++++	+	++++	+
	6	++++	+	++++	+
Recovery	1	++	+	+++	+
	2	Trace	0	+	0

The gross clinical quantitative estimate of urinary ketone bodies indicates a variability in the degree of starvation ketosis, being more severe in D.A. who also had a greater caloric expenditure and was grossly more obese. That acidosis was greater in D.A. is also reflected in the larger total solute load claiming removal by the kidneys. The measurement of urine solutes contains the substances derived from the ketosis of fasting, as well as the end products of the oxidation of protein and inorganic electrolytes removed with body water. Increased production of ammonia accompanies the addition of ketone acids to the renal excretion of acids. From the studies of Gamble, the larger total solute output for D.A. is taken to indicate a larger excretion of organic acids and of ammonia.

The simultaneous increases in plasma sp. gr., plasma protein concentration, hematocrit, hemoglobin, and red blood count are interpreted as indices of hemoconcentration. The hematological measurements alone would not justify this conclusion since a rise in red blood count could also cause a rise in hemoglobin and hematocrit. However, it would not be valid to interpret hemoconcentration as an index of water balance because of the possibility of a redistribution of ECW to the interstitial compartment and because of the hydrophilic property of tissue in fasting acidosis.

TABLE 9

CHANGES IN CLINICAL LABORATORY DATA DURING FASTING IN THE COLD ENVIRONMENT

Subject: H.B.

	Control[1]	Experimental[1]	Recovery[2]
Body Weight[3], Kg	69.09	63.72	65.71
Diet: Calories	3130	0	2323
CHO, gms	385	0	300
PRO, gms N	25.23	0	16.3
FAT, gms	106	0	74
Water Intake	2500	1000	2400
Caloric Output	2500	2800	2580
Urine			
Volume, cc.	1842	592	915
Nitrogen, gms	18.79	8.89	11.67
Sp. Gr.	1.022	1.024	1.021
Solutes, m-osM	1923	722	950
Osmolar Conc., osM/L	1.05	1.24	1.03
Chloride, gms, as Na Cl	21.05	1.25	6.23
Blood			
Sugar, mg %	107	78	103
Chloride, mg %, as Na Cl	496	410	450
CO_2 Content, vols %	62.0	58.1	70.4
NPN, mg %	40	41	36
Plasma Sp. Gr.[3]	1.0245	1.0279	1.0263
Plasma Protein[3], gms %	6.39	7.28	6.62
Hematocrit[3]	49	51	43
Hgb[3], gms	14.4	16.1	13.4
RBC[3], x 10^6	5.30	5.54	4.79

1. Daily average values for the last 3 days of control and experimental phases.
2. Daily average values for the first 3 days of the recovery phase.
3. Values for last day of control and experimental phases, 3rd day of recovery.

TABLE 10

CHANGES IN METABOLIC DATA DURING FASTING IN THE COLD CHAMBER

Subject: D.A.

	Control[1]	Experimental[1]	Recovery[2]
Body Weight[3], Kg	96.72	89.62	91.28
Diet: Calories	3050	0	2373
CHO, gms	395	0	311
PRO, gms N	22.13	0	16.15
FAT, gms	101	0	79
Water Intake	2500	1000	2150
Caloric Output	3200	3700	3080
Urine			
Volume, cc	2100	750	775
Nitrogen, gms	18.51	11.36	11.10
Sp. Gr.	1.022	1.027	1.021
Solutes, m-osM	1670	1020	810
Osmolar Conc., osM/L	0.81	1.37	1.04
Chloride, gms, as Na Cl	15.81	1.84	4.69
Blood			
Sugar, mg %	105	76	100
Chloride, mg%, as Na Cl	529	503	450
CO_2 Content, Vols %	57.8	53.6	65.2
NPN, mg %	38	34	30
Plasma Sp. Gr.[3]	1.0271	1.0286	1.0278
Plasma Protein[3], gms %	6.55	7.36	7.13
Hematocrit[3]	47	50.5	45
Hgb[3], gms	14.7	16.3	15.4
RBC[3], x 10^6	5.10	5.32	5.12

1. Daily average values of last 3 days.
2. Daily average values of first 3 days.
3. Values for last day of control and experimental phases, 3rd day of recovery.

The respiratory exchange data from which total caloric expenditures were computed are given in Table 11. Progressive limitation of voluntary activity was observed in the fasting subjects, average caloric expenditures decreasing from 3500 calories to 3000. The average daily caloric output for both subjects was 2800 calories, when expressed in terms of the standard 70 Kg. man. The maintenance of normal body temperatures and comfortable skin temperatures (Table 15) with only moderate activity in the cold environment is interpreted as a reflection of the adequacy of insulation provided by the clothing assembly and sleeping bag. Caloric expenditures calculated from a correlation of metabolic cost values (Haldane analyses) with time-activity data agrees well with the caloric output computed from total heat loss (Table 12).

Table 13 illustrates the hobbling effect of clothing upon the metabolic cost (26). This was an incidental observation; evidence is lacking from this data to definitely demonstrate the effect since the influence of the cold environment cannot be eliminated. The metabolic cost of a given activity at room temperature with the clothing assembly worn is a necessary control. The data show the absence of an increase in metabolic cost for those activities which are not affected appreciably by the amount of clothing; i.e., lying quietly and sitting. Whereas, the hourly expenditure for a 70 Kg. man walking 2.5 m.p.h. on a treadmill rose from room temperature values of 220 calories to 293 in the cold environment, an increase of 24 per cent.

A downward trend of the RQ toward 0.72 was observed with continued fasting (Table 14). There was greater lowering for activities involving caloric expenditures of the order of 250 cal/hr. as compared with those of about 100 cal/hr. An obvious explanation is increased combustion of fat in fasting, especially during exercise.

TABLE 11

SUMMARY OF RESPIRATORY EXCHANGE
DATA DURING FASTING IN THE COLD ENVIRONMENT

(Daily Averages for 6 Day Period)

Subject	Activity	Time Hrs.	Cal./Hr.	RQ	PMV L/min.
D.A.	Sleeping*	8.12	89	0.75	8.3
	Lying	6.53	102	0.75	8.3
	Sitting	0.93	115	0.74	10.0
	Standing	0.33	122	0.74	10.9
	Walking	6.47	262	0.74	20.9
	Treadmill	1.00	409	0.76	30.3
	Miscellaneous*	0.62	150	0.74	10.0
H.B.	Sleeping*	5.33	73	0.78	6.0
	Lying	9.98	83	0.78	6.0
	Sitting	0.83	100	0.72	6.3
	Standing	0.65	120	0.72	8.5
	Walking	6.20	198	0.73	12.6
	Treadmill	0.42	290	0.76	17.7
	Miscellaneous*	0.59	120	0.73	8.0

*Estimated

TABLE 12

SUMMARY OF ENERGY EXCHANGE DURING FASTING

(Daily Averages for 6 Day Period)

Subject	H.B.	D.A.
Caloric Output by Time-Activity Data	2805	3760
Caloric Output by Total Heat Loss		
H_{Cl}	1918	2695
E_l	280	444
E_S	268	220
A	190	302
W	140	193
	2796	3854

TABLE 13

METABOLIC COST OF ACTIVITIES

(Hobbling Effect of Clothing)

	H.B.		D.A.	
Temperature	+20°C.	-29°C.	+20°C.	-29°C.
Clothing	Temperate	Arctic	Temperate	Arctic
Activity	Cal./hr.	Cal./hr.	Cal./hr.	Cal./hr.
Lying Quietly	78	83	97	102
Sitting	94	100	113	115
Walking	149	198	235	262
Treadmill	205	290	324	409

TABLE 14

FASTING RESPIRATORY QUOTIENTS*

At Rest and With Moderate Activity

Test Day	Resting (100 Cal./Hr.)	Moderate Activity (250 Cal./Hr.)
Pre-test	0.83	0.82
1-2	0.78	0.77
3-4	0.78	0.73
5-6	0.75	0.72

*Average values of two subjects for lying quietly and walking on treadmill, 2.5 m.p.h., level.

TABLE 15

SKIN TEMPERATURES

(Average Values For 6 Day Period, °F.)

Area	H.B. Initial	H.B. Test Phase Av.	H.B. Test Phase Min.	D.A. Initial	D.A. Test Phase Av.	D.A. Test Phase Min.
Foot	80	73	62	90	69	55
Calf	87	83	79	88	79	71
Palm	90	69	61	92	71	61
Forearm	90	80	71	93	83	75
Abdomen	90	89	77	89	90	87
Weighted Average	88	84		89	85	

The components of the water exchange are summarized for the last 3 days of the 6 day fast in Table 16. Data obtained during the first three days are omitted because this period represents adjustment to the stress while approaching a "steady state". Measuring the other components of the water exchange permits an estimate of the daily loss of body water accompanying the removal of body fluid solutes. An average daily loss of approximately 300 cc. was observed. The estimations of BW for the individual subjects range rather widely from this average. The larger loss of body water from D.A. is explained in part by the greater surface area (2.22 sq. m. compared to 1.87 for H.B.) and by the larger caloric expenditure which is in turn reflected in the larger values for total solutes, Ur.W., and I.W. The average loss of BW is considerably less than that observed by Gamble (500 cc.) but the difference can be attributed largely to the greater W_{ox} made available as a result of a larger caloric expenditure (3150 calories compared to approximately 2000).

The average daily total solute output in the urine was found to be 871 milliosmoles. Calculation of the minimum urine water from this solute load gave an average requirement of 597 cc. or 509 cc. for a 70 Kg. individual. The minimum water intake necessary to prevent dehydration was computed from the Min. Ur. W., I.W., Wox and B.W. and found to average 952 cc. or 829 cc. in terms of the 70 Kg. standard man. Because of the wide range in the larger of the two components of obligatory water expenditure, I.W., Gamble has suggested estimating Min. W.I. on the basis of a constant I.W. of 1000 cc. Re-calculating the data from these subjects, the minimum water intake is defined as 909 cc. or 928 cc. per 70 Kg. per day. This value is somewhat higher than that found by Gamble (831 cc.) but his subjects were at rest and under ordinary environmental conditions. The results are in good agreement with those reported by Benedict (19) and Ivy (6). In the 31 day fast, Benedict's subject started with a daily allowance of 750 cc. of distilled water but this was increased to 900 cc. on the 11th day because of parched lips and a dry mouth. This quantity was continued to the end of the fast and the subject was in water balance without a dry mouth on a water intake of 900 cc. From the experiments conducted at the Naval Medical Research Institute, Ivy concluded that the minimum daily water requirement in starvation with enough carbohydrate to counteract ketosis (50-75 gms.) appeared to range from 825 to 1000 cc. in adults weighing 55 to 75 Kg. under ordinary environmental conditions (72°F; 30% RH) and with the physical activity of working at a desk.

TABLE 16

COMPONENTS OF THE WATER EXCHANGE

DURING FASTING, -29°C.

(Daily Averages of Last 3 Days of 6 Day Period)

Subject	H.B.	D.A.	Average
Caloric Deficit/day	2590	3710	3150
Water Intake	1000	1000	1000
Urine Volume	592	750	671
Urine Solutes, m-osM	722	1020	871
Urine N, gms	8.89	11.36	10.12
I.W.*	945	1142	1043
Fe W	0	0	0
Ur W	570	718	644
Wox*	330	440	385
B.W.	185	420	302
Min. Ur. W.	491	703	597
Min. W. I., Observed	921	984	952
IW = 1000	976	842	909

*Average daily values for 6 day period.

The essential data used to calculate the amount of body substance catabolized during fasting are presented in Table 17. In the absence of any feces passed, the calculated weight loss is equal to the sum of the body tissue consumed and the body water loss. The calculated weight loss agrees well with the observed body weight loss. The relatively high carbohydrate portion in the metabolic mixture might result from an artifically high RQ due to hyperventilation. The body tissue catabolized represents an average of 45 per cent of the total weight loss. The body water expenditure represents 55 per cent. The cumulative body water loss is an average of 5.96 per cent of the initial body water (based upon 70% of the body weight).

Results of urine analyses for adreno-cortical hormone-like substances during fasting are reported in Table 18. The 17-ketosteroid measurement is assumed to reflect the protein anabolic "N hormone" hormone of the adrenal cortex. The definite reduction in urinary 17-KS level in both subjects beginning with the 3rd day of fasting is interpreted to indicate a suppression of protein anabolism. The body sacrifices anabolism for the needed fuel or energy in fasting. The 11-oxycorticosteroid excretion is an index of the rate of production of the adrenal cortical "sugar hormone" (gluconeogenic, anti-anabolic). The values obtained are all within the normal range (0.10 - 0.44 mg/24 hrs.) but there is a tendency during fasting for a slight rise above the control levels. A rise of urinary 11-OCS assays has been reported in non-specific trauma "alarm reaction". Such a rise is interpreted as an effort on the part of the body to obtain energy from every available source by gluconeogenesis. The failure to observe a significant rise in the 11-OCS values during the experimental phase indicates the lack of sufficient stress reflecting the adequacy of clothing worn and the moderate activity performed.

TABLE 17

PARTITION OF BODY WEIGHT LOSS DURING FASTING

(Daily Averages For The 6 Day Period)

	H.B.	D.A.
Total Caloric Output	2800	3760
Weighted Av. RQ	0.76	0.75
Weighted Av. Cal/LO_2	4.73	4.74
Av. Urine N, gms	9.79	11.83
Total O_2 Consumption, L.	592	793
Total CO_2 Production, L.	450	595
Metabolic Mixture		
CHO, gms	108	119
PRO, gms	61	74
FAT, gms	225	316
Body Tissue Loss, gms	394	509
Body Water Loss, gms	491	657
Calculated Wt. loss, gms	885	1166
Weight Loss, Observed, gms	894	1183

TABLE 18

ADRENO-CORTICAL HORMONE-LIKE SUBSTANCES IN URINE

DURING FASTING EXPERIMENTS*

(24 Hr. Output)

Date	Phase	Day	H.B. 17-KS mg	H.B. 11-OCS mg	D.A. 17-KS mg	D.A. 11-OCS mg
11/3/47	Control	1	14.4	0.22	21.9	0.32
11/4/47		2	14.6		25.2	
11/10/47	Experimental	1	15.7	0.40	20.8	0.27
11/11/47		2	14.1	0.19	16.6	
11/12/47		3	9.0	0.33	9.6	0.41
11/13/47		4	8.8		9.6	
11/14/47		5	7.5		7.3	
11/15/47		6	6.7	0.19	9.6	0.37
11/16/47	Recovery	1	10.6		9.3	
11/17/47		2	8.8	0.26	11.3	0.31

* Analyses performed at Massachusetts General Hospital through the courtesy of Dr. Nathan B. Talbot. 17-KS = 17-Ketosteroids, 11-OCS = 11-Oxycorticosteroids.

B. EXPERIMENTS WITH USAF EMERGENCY RATION, DEVELOPMENTAL, NO. 1

1. Cold Environmental Study

The data obtained from two subjects during consumption of USAF Emergency Ration, Developmental No. 1, (USAF-ER-1) and a restricted water intake while residing continuously in a cold environment (-29°±3°C.) for 9 days are summarized in Tables 19-24.

Alterations in the clinical laboratory data are given in Tables 19 and 20. The average cumulative loss of body weight represented 4.15 per cent. Although the increased difference between W.I. and Ur. Vol. during the first 3 days of recovery is not as great as that noted in the fasting experiment, a physiological need for water is implied by this difference. The average value (first 6 days; compare with fasting) found for the negative nitrogen balance, -2.89 gms., represents the daily catabolism of approximately 18 gms. of body protein during the first 6 days.

The urinary nitrogen and total solute output for subject H.B. are approximately the same during metabolism of the test ration as were obtained for the same subject during fasting. This obtained despite a daily caloric expenditure of 500 calories more than that during fasting. Beginning with the second day of the experimental phase, both subjects developed a glycosuria, passing on the average 4.6 gms. of reducing substances per day. Considering the small quantity of carbohydrate ingested at any one time and the lack of actual exposure to the cold environment (adequate clothing), the possibilities of alimentary glycosuria and "cold nephrosis" do not appear to offer satisfactory explanation for this observation. Both subjects began passing occasional hyaline or granular casts, mucous shreds and white blood cells in the urines of the second experimental day. This cleared up promptly in the recovery phase with larger water intake. These same microscopic findings were noted in the fasting study. No albumin or acetone were detected in the urines.

No evidence of hemoconcentration during the test phase was demonstrated in the hematocrit, hemoglobin concentration or red blood count. The reduction in these hematological indices after three days of recovery may reflect an increase in blood volume with re-hydration. A striking lymphocytosis was observed in subject H.B. On the second day in the cold chamber, 71 per cent lymphocytes were present and 63 per cent on the fourth day. The relation of adrenal cortical function to the lymphoid tissues in response to stress offers intriguing speculation for the genesis of the lymphocytosis.

In the lower graph of Figure 10 are presented the course of 24-hour urine volumes, total urine nitrogen and total urine solutes (subject H.B.) through the three successive phases. The urine volumes averaged 541 cc. during the last 6 days of "deprivation" in the cold chamber. The total urine solutes averaged 763 milliosmols. The delay

in return to control values for the urine volume and total urine nitrogen and the more positive nitrogen balance in the recovery phase are interpreted to indicate the re-hydration and nitrogen repletion of convalescence. Nitrogen balance is portrayed in the upper bar graph, Figure 10. The large urinary nitrogen loss on the first day of the test phase may be the result of a "lag effect" from the high nitrogen intake during the control phase. The average nitrogen balance during the last six days of the experimental period was -1.82 gms. The apparently markedly positive nitrogen balances recorded for the control and recovery phases may be artificial for two reasons. Approximately 1 gram of the dietary nitrogen is lost in the feces and should be deducted from the recorded balances. Also, the values used for protein content of the E Ration components fed during these phases represented average analyses from a number of samples, but the individual analyses varied as much as ± 50 per cent from the average. Such lack of uniformity in the composition of individual cans of rations is the result of the impracticality of processing the items in a homogeneous state and yet retain a high order of acceptability. A false high nitrogen balance would result if the actual protein content was less than the average value used in the calculation. This error is not important to the problem at hand since the purpose of the standard regimen of the control phase is to achieve a relatively "stable metabolic state", not necessarily nitrogen equilibrium.

TABLE 19

CHANGES IN CLINICAL LABORATORY DATA DURING CONSUMPTION OF USAF - EMERGENCY RATION, DEVELOPMENTAL NO. 1 WHILE RESIDING IN THE COLD ENVIRONMENT, -29° ±3°C.

Subject: H.B.

	Control[1] Phase	Experimental[2] Phase	Recovery[3] Phase
Body Weight, Kg.	68.460	65.327	67.350
Diet, Calories	3157	1948	3106
CHO, gms	409	318	411
PRO, gms N	24.0	6.66	22.2
FAT, gms	102	57	102
Water Intake, cc.	2500	800	2500
Caloric Output	2990	2900	2600
Urine			
Volume, cc.	1765	562	1158
Nitrogen, gms	17.4	8.73	12.5
Sp. Gr.	1.020	1.032	1.024
Solutes, m-osM	1614	779	1435
Osmolar Conc., OsM/L.	0.91	1.39	1.25
Sugar, gms	0	4.4	0
Blood			
Sugar, mg %	100	95	90
NPN, mg %	42	39	44
Hematocrit	47	47	42
Hemoglobin, gms	14.4	15.6	13.4
RBC, x 10^6	5.37	4.99	4.89
WBC, x 10^3	10.0	11.1	8.6
Lymphocytes, %	41	60	36

1. Daily average values for last 3 days.
2. Daily average values for the fourth through the sixth days.
3. Daily average values for the second through the fourth days.

TABLE 20

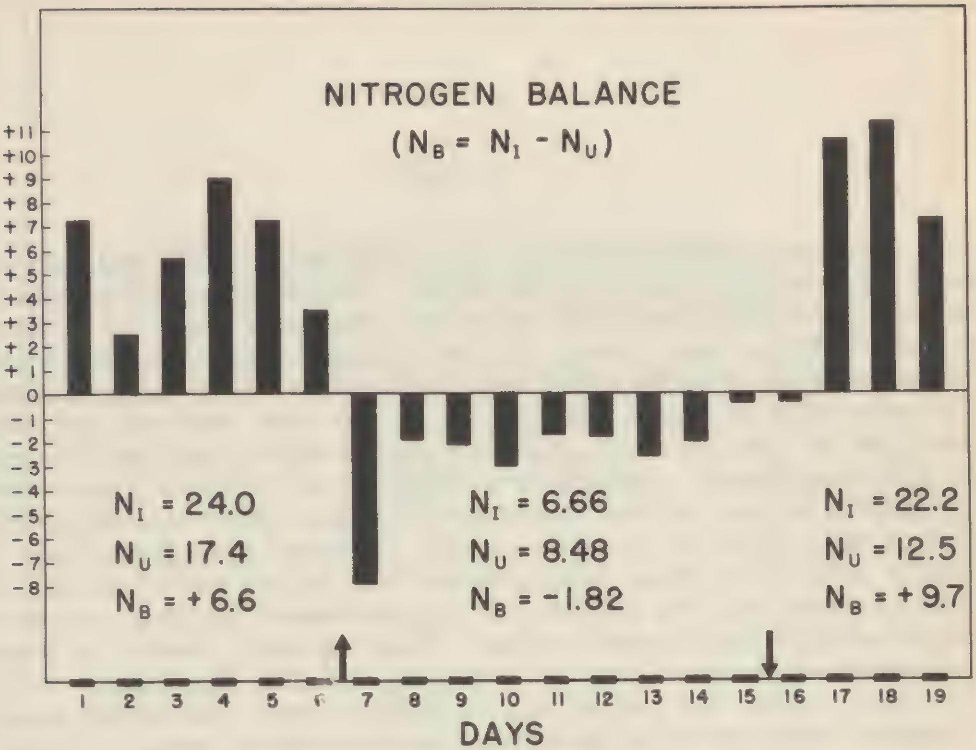
CHANGES IN CLINICAL LABORATORY DATA DURING CONSUMPTION OF USAF - EMERGENCY RATION, DEVELOPMENTAL NO. 1 WHILE RESIDING IN THE COLD ENVIRONMENT, -29° ±3°C.

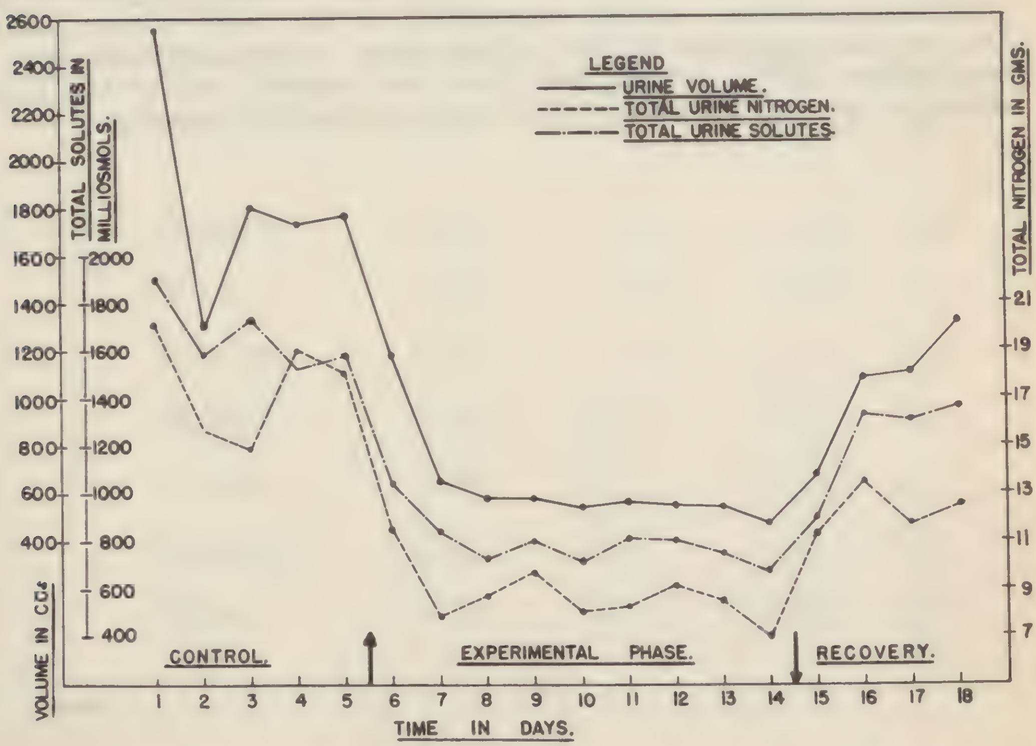
Subject: H.P.

	Control[1] Phase	Experimental[2] Phase	Recovery[3] Phase
Body Weight, Kg	64.670	62.264	62.400
Diet, Calories	2600	1877	2636
CHO, gms	358	308	408
PRO, gms N	18.17	6.56	14.06
FAT, gms	79	54	72
Water Intake, cc.	2500	955	2500
Caloric Output	2500	2580	2400
Urine			
Volume, cc.	1646	578	1493
Nitrogen, gms	13.14	9.60	13.23
Sp. Gr.	1.017	1.033	1.018
Solutes, m-osM	1080	779	1299
Osmolar Conc., osM/L.	0.70	1.39	0.88
Sugar, gms	0	4.8	0
Blood			
Sugar, mg %	108	98	110
NPN, mg %	39	36	38
Hematocrit	46	51	45
Hemoglobin, gms	15.4	16.1	14.8
RBC, x 10^6	5.01	5.79	5.43
WBS, x 10^3	4.3	5.5	4.0
Lymphocytes, %	45	45	43

1. Daily average values for last 3 days.
2. Daily average values for the fourth through the sixth day.
3. Daily average values for the second through the fourth day.

FIGURE 10





COURSE OF URINE VOLUME, TOTAL URINE NITROGEN, AND TOTAL URINE SOLUTES

The respiratory exchange data from which total caloric expenditures were computed are given in Table 21. The average daily caloric output for both subjects was 2785 calories, when expressed in terms of the standard 70 Kg. man. Again it may be concluded that the maintenance of normal body temperatures and comfortable "skin temperatures" (table 23) with only moderate activity indicates the adequacy of insulation provided by the clothing assembly and sleeping bag for the conditions of the experiment. Caloric expenditures calculated from a correlation of metabolic cost values (Haldane analyses) with time-activity data agrees well with the caloric output computed from total heat loss (table 22). The "skin temperatures" as registered with the resistance thermometers are not as precise a measurement as that provided by copper-constantan thermocouples. They probably record a temperature intermediate between that of the skin and the first layer of clothing. For this reason the values are somewhat lower than those usually observed with the more sensitive thermocouples, even initially before exposure to the cold. The average "skin temperatures" (table 15) observed during the fasting experiment were several degrees higher than those recorded during consumption of the test ration (table 23). This may be explained by the colder range in the environmental temperature (±3°C. cf. ±0.5°C) from the average, and by the accidental omission of the felt inner soles from the mukluk assembly.

TABLE 21

SUMMARY OF RESPIRATORY EXCHANGE DATA
DURING CONSUMPTION OF USAF EMERGENCY RATION
DEVELOPMENTAL NO. 1, IN THE COLD ENVIRONMENT

(Daily Averages For The 4th Through The 6th Days)

Subject	Activity	Time Hrs.	Cal./hr.	RQ	PMV L/min.
H.B.	Sleeping*	6.83	73	0.83	6.0
	Lying	4.33	83	0.83	6.3
	Sitting	3.16	100	0.83	6.8
	Eating*	1.94	120	0.83	8.5
	Walking	6.16	168	0.83	13.9
	Treadmill	0.83	270	0.83	21.3
	Catch	0.78	320	0.86	31.2
H.P.	Sleeping*	6.58	60	0.88	6.8
	Lying	3.66	70	0.88	6.8
	Sitting	3.41	90	0.88	7.0
	Eating*	1.92	115	0.88	8.5
	Walking	7.00	152	0.88	13.4
	Treadmill	0.64	247	0.89	18.0
	Catch	0.77	242	0.89	20.0

* Estimated

TABLE 22

SUMMARY OF ENERGY EXCHANGE
DURING CONSUMPTION OF USAF - EMERGENCY RATION,
DEVELOPMENTAL NO. 1, IN THE COLD ENVIRONMENT.

(Daily Averages for the 9 Day Period)

Subject	H.B.	H.P.
Caloric Intake	1860	1920
Caloric Output by Time-Activity Data	3035	2650
Caloric Output by Total Heat Loss		
H_{Cl}	2128	2007
E_L	352	344
E_S	92	110
A	220	218
W	147	141
	2939	2820

TABLE 23

SKIN TEMPERATURES

(Average Values for the 9 Day Period)

Area	H.B. Initial	H.B. Test Phase Av.	H.B. Test Phase Min.	H.P. Initial	H.P. Test Phase Av.	H.P. Test Phase Min.
Foot	77	67.5	58	79	66	54
Calf	87	80.3	75	87	74	68
Palm	91	69.5	60	88	71	61
Forearm	88	78.6	70	90	84	78
Abdomen	88	86.7	77	89	89	85
Weighted Average	87	81.5		87.7	82	

The components of the water exchange are summarized for the 4th through the 6th day of ration consumption in Table 24. The body protein and body fat sparing effects of the ration result in a reduction of physiologically available intracellular body water. The conservation of body water is indicated by the average daily loss of only 83 cc. This may be regarded as desirable from the standpoint of the future availability of ICW should circumstances of the survival experience involve subsequent fasting. However, the reduction of available ICW accompanying the protection of body tissue may lead to dehydration in the presence of a limited water intake. In the presence of osmolar concentrations of 1.39, it is assumed that body water is not being withdrawn beyond the physiologically available quantity (see discussion).

The average daily total solute output in the urine was found to be 779 milliosmoles. Calculation of the minimum urine water from this solute load gave an average requirement of 516 cc. or 545 cc. for a 70 Kg. individual. The minimum water intake necessary to prevent dehydration was computed from measurements of the other components of the water exchange and found to average 883 cc. or 932 cc. in terms of the 70 Kg. standard man. To facilitate comparison of the data with that obtained during fasting, a constant value, 850, was assigned to I.W. for subject H.B. Re-calculating the data, the minimum water intake is defined as 826 cc. for fasting, and 889 cc. for the ration. This would represent a daily loss of approximately 60 cc. of B.W. beyond the physiologically available quantity. In terms of its influence upon survival expectancy, the dehydration from such a slight loss of B.W. is regarded as negligible.

TABLE 24

COMPONENTS OF THE WATER EXCHANGE
DURING CONSUMPTION OF USAF EMERGENCY RATIONS
DEVELOPMENTAL NO. 1, -29°C.

(Daily Averages for the 4th Through the 6th Days)

Subject	H.B.	H.P.	Average
Caloric Intake	1948	1877	1912
Caloric Deficit	965	705	836
Water Intake[1]	830	985	907
Urine Volume, cc.	562	578	570
Urine Solutes, m-osM	779	779	779
Urine N, gms	8.73	9.60	9.16
I.W.[2]	765	779	770
Fe. W.	20	20	20
Ur. W.	531	548	539
Wox.[2]	378	345	346
B.W.	105	60	83
Min. Ur. W.	505	527	516
Min. W.I., Observed	804	962	883
I.W. = 850	889	1033	961

1. Includes preformed water content of ration
2. Average values for 9 day period

The essential data used to calculate the amount of body substance catabolized (metabolic mixture minus the ration) during consumption of the developmental emergency ration are summarized in Table 25. A stool was passed every three days, weighing on the average 100 gms. with a water content of 60 per cent. The calculated daily weight loss is equal to the sum of the body tissue consumed, fecal solids and body water loss; this sum agrees well with the observed weight loss. The body tissue catabolized represents an average of 41 per cent of the total weight loss. The body water expenditure represents 59 per cent. The cumulative body water loss is estimated to average 3.42 per cent of the initial body water (70% of the body weight).

TABLE 25

PARTITION OF BODY WEIGHT LOSS
DURING CONSUMPTION OF USAF EMERGENCY RATION,
DEVELOPMENTAL NO. 1, -29°C.

(Daily Averages for the 9 Day Period)

	H.B.	H.P.
Total Caloric Output	3035	2650
Weighted Av. RQ	0.83	0.88
Weighted Av. Cal/L.O_2	4.86	4.90
Av. Urine N, gms	8.77	9.36
Total O_2 Consumption, L.	625	541
Total CO_2 Production, L.	518	476
Metabolic Mixture		
CHO, gms	294	371
PRO, gms	55	59
FAT, gms	168	93
Body Tissue Loss, gms	131	112
Fecal Solids, gms	13	10
Body Water Loss, gms	195	157
Calculated Weight Loss, gms	336	279
Weight Loss, observed, gms	346	267

2. Room Temperature Study

The data obtained from three subjects during consumption of a test ration (USAF - ER - 1) and a restricted water intake while going about their usual activities at room temperatures (+20° ±3°C., RH: 60-70%) for a period of 10 days are summarized in Tables 26-29. Unfortunately the military duties of the test subjects did not permit their confinement in the constant temperature room. This lack of control necessitated estimation of caloric expenditure from standard metabolic cost tables during the experimental phase, as well as during the control and recovery periods. Estimations of I.W., Wox and B.W. were not possible.

The changes in clinical laboratory data are presented in Tables 26-28. The average cumulative loss of body weight represented 3.96 per cent. Again the increased difference between W.I. and Ur. Vol. during the first 3 days of recovery implies a physiological need for water. The approximate return of urine chloride excretion to control values within 3 days during recovery indicates that salt reserves were less depleted than during the fasting study. The ration provided approximately 3 to 4 gms of sodium chloride (analysis of ration not completed at time of this writing). This would explain the level of urinary chloride excretion during the experimental phase. The average value found for the negative nitrogen balance, -2.0 gms, represents the daily catabolism of approximately 13 gms of body protein during the first 6 days.

Considering individual variations, the average urinary nitrogen and the total solute output agree well with the results obtained during consumption of the same ration by the two other subjects in the cold environment. Partial explanation for the failure to observe a reduction in total solute output during consumption of the ration, despite its protein sparing and anti-ketogenic effects, is found in the salt content of the ration. The daily urinary excretion of 4 gms. Na Cl above the level of fasting would increase the solute load by approximately 130 milliosmoles. The urinary nitrogen loss is less than that observed during fasting, but greater than that obtained by Gamble with a pure carbohydrate ration (9). Thus, the urinary nitrogen contributes in a small way to the maintenance of the solute load. The stress of limited water intake upon the kidneys and urinary bladder was again reflected in the appearance of mucous shreds and occasional granular casts and white blood cells. No sugar or reducing substances, albumin or acetone were detected in the urines of these subjects. These negative findings help to eliminate the ration as the cause of the glycosuria noted in the previous study.

The minor changes in hematocrit, hemoglobin concentration, red blood count, plasma protein and sp. gr. offer no significant evidence of hemoconcentration. The slight rises in blood NPN subsided before the end of the experimental period and have no significance.

TABLE 26

CHANGES IN CLINICAL LABORATORY DATA DURING CONSUMPTION OF USAF - EMERGENCY RATION, DEVELOPMENTAL NO. 1 ROOM TEMPERATURES, RH: 60-70%.

Subject: D.A.

	Control[1] Phase	Experimental[2] Phase	Recovery[3] Phase
Body Weight[4], Kg	96.51	92.25	94.41
Diet, Calories	3072	1948	3158
CHO, gms	413	318	435
PRO, gms N	21.33	6.66	20.77
FAT, gms	98	56	99
Water Intake, cc.	2500	800	2500
Caloric Output[5]	3300	3050	3570
Urine			
Volume, cc.	1797	580	936
Nitrogen, gms	14.75	7.81	12.21
Sp. Gr.	1.017	1.028	1.027
Solutes, m-osM	1389	723	1033
Osmolar Conc., osM/L.	0.79	1.25	1.16
Chloride, gms, as Na Cl	11.87	6.48	11.00
Blood			
NPN, mg %	33	39	40
Serum Protein[4], gms %	5.6	6.5	6.4
Plasma Protein[4], gms %	5.23	6.87	6.89
Plasma Sp. Gr.[4]	1.0224	1.0269	1.0271
Hematocrit[4]	46	45	45
Hemoglobin[4], gms	14.6	14.9	14.2
RBC[4], x 10^6	5.15	4.93	5.15

1. Daily average values for last 3 days.
2. Daily average values for the 4th through the 6days.
3. Daily average values for first 3 days.
4. Values for last day of control and experimental phases, 3rd day of recovery.
5. Estimated from standard metabolic cost tables (Field Manual, Harvard Fatigue Laboratory).

TABLE 27

CHANGES IN CLINICAL LABORATORY DATA DURING CONSUMPTION OF USAF - EMERGENCY RATION DEVELOPMENTAL NO. 1 ROOM TEMPERATURES, RH: 60-70%

Subject: D.D.

	Control[1] Phase	Experimental[2] Phase	Recovery[3] Phase
Body Weight[4], Kg.	86.47	83.20	84.46
Diet, Calories	3053	1948	3161
CHO, gms	395	318	432
PRO, gms N	23.52	6.66	21.7
FAT, gms	98	56	98
Water Intake, cc.	2500	800	2500
Caloric Output[5]	3600	3250	3200
Urine			
Volume, cc.	1745	563	912
Nitrogen, gms	15.85	9.61	9.87
Sp. Gr.	1.018	1.029	1.028
Solutes, m-osM	1461	776	1117
Osmolar Conc., osM/L	0.85	1.37	1.24
Chloride, gms, as Na Cl	12.69	5.46	10.32
Blood			
NPN, mg %	38	42	41
Serum Protein[4], gms %	5.9	6.3	6.2
Plasma Protein[4], gms %	6.04	6.69	7.13
Plasma Sp. Gr.[4]	1.0246	1.0267	1.0278
Hematocrit[4]	48	47	47
Hemoglobin[4], gms	15.3	14.9	14.6
RBC[4], x 10^6	4.81	4.81	5.46

1. Daily average values for last 3 days.
2. Daily average values for the 4th through the 6th days.
3. Daily average values for first three days.
4. Values for the last day of control and experimental phases; 3rd day of recovery.
5. Estimated from standard metabolic cost tables.

TABLE 28

CHANGES IN CLINICAL LABORATORY DATA DURING CONSUMPTION
OF USAF - EMERGENCY RATION DEVELOPMENTAL NO. 1
ROOM TEMPERATURES, RH: 60-70%

Subject: S.W.

	Control[1] Phase	Experimental[2] Phase	Recovery[3] Phase
Body Weight[4], Kg.	66.91	64.44	65.44
Diet, Calories	3083	1948	3090
CHO, gms	398	318	420
PRO, gms N	21.06	6.66	24.16
FAT, gms	106	57	97
Water Intake, cc.	2500	800	2500
Caloric Output[5]	2400	2700	2600
Urine			
Volume, cc.	1445	452	945
Nitrogen, gms	13.45	7.16	8.29
Sp. Gr.	1.022	1.028	1.026
Solutes, m-osM	1306	607	778
Osmolar Conc., OsM/L	1.00	1.34	0.95
Chloride, gms, as Na Cl	12.35	4.44	9.94
Blood			
NPN, mg %	40	43	40
Serum Protein[4], gms %	6.1	6.3	6.2
Plasma Protein[4], gms %	6.38	6.83	6.96
Plasma Sp. Gr.[4]	1.0256	1.0268	1.0273
Hematocrit[4]	49	48	47
Hemoglobin[4], gms	15.9	15.8	15.8
RBC[4], x 10^6	5.11	5.28	5.15

1. Daily average values for last 3 days.
2. Daily average values for the 4th through the 6th days.
3. Daily average values for the first 3 days.
4. Values for the last day of control and experimental phases, 3rd day of recovery.
5. Estimated from standard metabolic cost tables.

The components of the water exchange are summarized for the 4th through the 6th days of ration consumption in Table 29. Estimations of I.W., Wox. and B.W. were not possible because of the necessity for the subjectsto perform their usual military duties. Estimation of minimum urine water was obtained from the equation: Min. W.I. = Min. Ur. W + (WI - Ur.W). Examination of figure 18 will facilitate understanding the following derivation of this equation:

1. Min. W.I. = (I.W. + Min. Ur.W. + Fe.W.)-(Wox + B.W.)

B.W. = (I.W. + Ur.W. + Fe.W.) - (W.I. + Wox.)
Solving for, URW = (W.I. + Wox. + B.W.) -(I.W. + Fe.W.)
W.I. - Ur.W. = (I.W. + Fe.W.) - (Wox. + B.W.)

Min.W.I. = Min. Ur. W. + (W.I. - Ur.W.), or
= W.I. - (Ur.W. - Min. Ur.W.)

In the presence of average maximum osmolar concentrations of 1.32, the above equation is applicable and it may be assumed that body water is not being withdrawn beyond the physiologically available quantity. The average daily total solute output in the urine was found to be 702 milliosmoles. This solute load defined an average obligatory renal water requirement of 480 cc. or 402 cc. for a 70 Kg. individual. The minimum water intake necessary to prevent dehydration was computed from the above equation and found to average 802 cc. or 655 cc. for the standard 70 Kg. man.

An approximation of the other components of the water exchange may be obtained by assuming the caloric deficit, beyond that derived from body protein, is met by the consumption of body fat. The negative nitrogen balance during the 4th through the 6th days, -1.53 gms., represents the catabolism of 9.56 gms of body protein, equivalent to 39 calories. Thus, the calories derived from body fat equal 1160-39 = 1121 calories, or 121 gms. of body fat. The partition of body weight loss as indicated below yields the approximate daily body water loss:

Av. observed weight loss, gms.	= 333
Approx. loss of body substances, gms.	
body protein	= 10
body fat	= 121
fecal solids*	= 12
	143
Approx. loss of B.W., gms.	190

Water of oxidation, computed from the metabolic mixture of the ration plus the body protein and body fat consumed (CHO-318, PRO-51.2, and FAT-178), is estimated to average 422 cc. The average insensible water loss is approximated from these estimations of the other components of the water balance by application of the formula:

*Estimated from an assumed stool weight of 100 gms/3 days with 60% water.

2. $I.W. = (B.W. + Wox + Min.\ W.I.) - (Min.\ Ur.\ W. + Fe.W.)$

$= (190 + 422 + 802) - (480 + 20)$

$I.W. = 914$ cc.

Based upon the above approximations, the body tissue catabolized represents an average of 39 per cent of the observed weight loss; the body water expenditure 57 per cent. The body water loss would be approximately 3 per cent of the initial body water.

TABLE 29

COMPONENTS OF THE WATER EXCHANGE* DURING CONSUMPTION OF USAF EMERGENCY RATION DEVELOPMENTAL NO. 1 ROOM TEMPERATURES, RH: 60-70%

(Daily Average Values For the 4th Through the 6th Days)

Subject	D.A.	D.D.	S.W.	Average
Caloric Intake	1948	1948	1948	1948
Caloric Deficit	1104	1592	784	1160
Water Intake[1]	830	830	830	830
Urine Volume, cc.	580	563	452	532
Urine Solutes, m-osM	723	776	607	702
Urine N, gms	7.81	9.61	7.16	8.19
Ur.W.	554	536	432	507
Min. Ur. W.	493	530	416	480
Min. W. I.[2]	769	824	814	802

* Estimations of IW, Wox and BW were not possible; military duty of subjects did not permit confinement in constant temperature room.

1. Includes preformed water content of the ration.

2. Min. W. I. = Min. Ur. W. + (W.I. - Ur.W.).

C. EXPERIMENTS WITH USAF EMERGENCY RATION, DEVELOPMENTAL NO. 2

1. Room Temperature Study

The data obtained from two subjects during consumption of the second developmental emergency ration (USAF - ER - 2) and a restricted water intake while residing continuously in the constant temperature room (+22° ±2°C., RH: 50-60%) for 7 days are summarized in Tables 30-34. The average cumulative loss of body weight represented 5.53 per cent. The difference between W.I. and Ur. Vol. during the first three days of recovery was not nearly as great as those encountered in the previous experiments. This may be the result of the reduced water intake (1500 cc. instead of 2500) used during the control and recovery periods. The purpose of the reduction in W.I. during these phases was to achieve greater stability in the urine volumes.

The urinary nitrogen loss for subject D.A. was approximately 2.0 gms. more per day than that observed during his consumption of the first developmental test ration. Accompanying this was an increase in total urine solutes (138 milliosmoles). The greater osmolar concentration (1.42 compared to 1.25) is interpreted to reflect greater stress upon the kidney's capacity to conserve body water. This may result from either or both of the following: (a) an increase solute load derived from the products of metabolism, or (b) an increase in insensible water loss. In this particular subject, it would appear that both factors contributed to the stress. The variation in results encountered in this type of metabolic study is illustrated by the data obtained on H.H. The urinary nitrogen loss and total urine solute output for subject H.H. compare well with the average results obtained with the first developmental test ration (USAF - ER - 1).

The average value found for the negative nitrogen balance, -1.24 gms, represents the daily catabolism of approximately 8 gms of body protein during the first 6 days.

The comments on urinary chloride excretion presented with the results of the previous experiment would appear to explain the findings given in Tables 30-31. The stress of limited water intake upon the kidneys and urinary bladder was again indicated by the microsopic examination of the urine sediment which showed mucous shreds and occasional casts and white blood cells. No sugar, albumin or acetone were detected in the urines.

No evidence of hemoconcentration was revealed in the hematological indices, nor was there any significant retention of blood non-protein nitrogen.

The respiratory exchange data from which total caloric expenditures were computed are given in Table 32. The average daily caloric output for both subjects was approximately 2500 calories, or 1900 calories when expressed in terms of the standard 70 Kg. man. Inspection of the time-activity data confirms the low order of caloric expenditure. The question arises--if the caloric expenditure had been considerably greater, would the nitrogen balance become significantly less favorable?

TABLE 30

CHANGES IN CLINICAL LABORATORY DATA DURING CONSUMPTION
OF USAF EMERGENCY RATION, DEVELOPMENTAL NO. 2
ROOM TEMPERATURE +22° ±2°C.
RH: 50-60%

Subject: D.A.

	Control[1] Phase	Experimental[2] Phase	Recovery[3] Phase
Body Weight[4], Kg	97.452	91.116	94.488
Diet, Calories	3016	2134	3072
CHO, gms	467	317	475
PRO, gms N	15.7	8.06	15.9
FAT, gms	85	75	86
Water Intake, cc.	1500	800	1500
Caloric Output	3490	2750	2900
Urine			
Volume, cc.	1150	608	992
Nitrogen, gms	11.95	9.85	13.19
Sp. Gr.	1.023	1.033	1.024
Solutes, m-osM	1235	861	1107
Osmolar Conc., OsM/L	1.10	1.42	1.13
Chloride, gms, as Na Cl	9.24	5.49	7.45
Blood			
NPN, mg %	41	41	34
Chloride, mg% as Na Cl	450	410	478
Sugar, mg%	94	90	90
Hematocrit[4], %	46.5	46.5	43.0
Hemoglobin[4], gms	15.9	15.4	14.8
RBC[4], x 10^6	5.16	6.00	5.11

1. Daily average values for last 3 days.
2. Daily average values for the 4th through the 6th day.
3. Daily average values for first three days.
4. Values for the last day of control and experimental phases; 3rd day of recovery.
5. Estimated from standard metabolic cost tables.

TABLE 31

CHANGES IN CLINICAL LABORATORY DATA DURING CONSUMPTION OF USAF EMERGENCY RATIONS, DEVELOPMENTAL NO. 2
ROOM TEMPERATURE +22° ±2°C.
RH: 50-60%

Subject: H.H.

	Control[1] Phase	Experimental[2] Phase	Recovery[3] Phase
Body Weight[4], Kg	86.688	82.730	84.280
Diet, Calories	3255	2147	2911
CHO, gms	477	316	458
PRO, gms N	15.9	8.12	16.02
FAT, gms	101	77	75
Water Intake, cc.	1500	800	1500
Caloric Output	3160	2300	2700
Urine			
Volume, cc.	1018	482	827
Nitrogen, gms	11.37	7.98	11.23
Sp. Gr.	1.027	1.037	1.027
Solutes, m-osM	1182	705	1016
Osmolar Conc., osM/L	1.19	1.46	1.23
Chloride, gms, as Na Cl	10.3	4.41	6.75
Blood			
NPN, mg %	38	40	34
Chloride, mg %, as Na Cl	478	478	450
Sugar, mg %	98	89	98
Hematocrit[4], %	47	46	45
Hemoglobin[4], gms	15.4	15.4	15.4
RBC[4], x 10^6	5.29	5.01	5.12

1. Daily average values for last 3 days.
2. Daily average values for the 4th through the 6th day.
3. Daily average values for first three days.
4. Values for the last day of control and experimental phases; 3rd day of recovery.
5. Estimated from standard metabolic cost tables.

TABLE 32

SUMMARY OF RESPIRATORY EXCHANGE DATA
DURING CONSUMPTION OF USAF EMERGENCY RATION, DEVELOPMENTAL NO. 2
ROOM TEMPERATURE +22°C ±2°C., RH: 50-60%

(Daily Averages for the 4th Through the 6th Days)

Subject	Activity	Time Hrs.	Cals/Hr.	RQ	PMV 1/min.
D.A.	Sleeping*	9.83	90	0.82	6.7
	Lying	1.42	100	1.00	7.9
	Reading	6.86	100	0.84	7.9
	Sitting	0.57	110	0.88	8.0
	Eating*	1.64	120	0.89	10.0
	Writing	0.61	125	0.88	
	Cards	0.28	130	1.00	10.0
	Walking	2.29	225	0.80	15.5
	Treadmill	0.49	300	0.92	22.0
H.H.	Sleeping*	8.70	70	0.84	5.5
	Lying	1.64	80	0.87	6.5
	Reading	6.77	80	0.92	6.0
	Sitting	1.64	103	0.93	8.0
	Eating*	1.50	115	0.88	10.0
	Writing	0.65	125	0.89	10.0
	Cards	0.31	125	0.88	9.5
	Walking	2.27	190	0.80	11.4
	Treadmill	0.53	245	0.92	17.0

* Estimated

The components of the water exchange are summarized for the 4th through the 6th days of ration consumption in Table 33. Some mechanical difficulty was encountered in regulating the temperature within the chamber during the first three days of this study. As a consequence an interesting correlation between I.W. and B.W. with environmental temperature was demonstrated. The figures tabulated below represent the average daily values for the first three days as compared with the second three days.

Days	Temperature	I.W.	B.W.
1 - 3	+79° ± 4°F.	1288	811
4 - 6	+75° ± 4°F.	1144	540

This change cannot be completely attributed to the environmental temperature since the trend would be a reduction of these components as adjustment to the stress of limited water intake took place.

The average body water loss is considerably higher than that observed in the previous experiments, but this is also accompanied by a proportionately higher "insensible water loss". In the presence of osmolar concentrations of 1.42, the possibility arises that body water is being withdrawn beyond the physiologically available quantity. However, as will be pointed out later, the values obtained by the freezing point technique used are probably in error. The error arising from diluting the urines and supercooling would give false high osmolar concentrations. Thus, the observed osmolar concentration, 1.42, is probably too high and B.W. is probably not being withdrawn beyond the physiologically available quantity.

The average daily total solute output in the urine was found to be 783 milliosmoles. Calculation of the minimum urine water from this solute load give an average requirement of 512 cc. or 390 cc. for a 70 Kg individual. The minimum water intake necessary to prevent dehydration was computed to average 832 cc. or 635 cc. per 70 Kg. per day. The validity of such a conversion on the basis of body weight when the actual weight varies so widely from 70 Kg. in a small group of subjects is questionable.

The essential data used to calculate the amount of body substance catabolized (metabolic mixture minus the ration) during consumption of the second developmental emergency ration are presented in Table 34. The calculated daily weight loss agrees well with the observed changes in body weight. The body tissue catabolized represents an average of 12 per cent of the total weight loss; the body water loss represents 86 per cent. The cumulative body water loss during the 7 day period is estimated to average 6.9 per cent of the initial body water (70% of body weight). Thus, the moderate thirst complained of by these subjects was accompanied by a significant loss of body water which is largely ascribed to extrarenal water expenditure.

TABLE 33

COMPONENTS OF THE WATER EXCHANGE
DURING CONSUMPTION OF USAF - EMERGENCY RATION: DEVELOPMENTAL NO. 2
ROOM TEMPERATURE +22° ±2°C., RH: 50-60%

(Daily Average Values for the 4th Through the 6th Days)

Subject	D.A.	H.H.	Average
Caloric Intake	2134	2147	2140
Caloric Deficit	614	150	382
Water Intake*, cc.	836	835	835
Urine Volume, cc.	608	482	545
Urine Solutes, m-osM	861	705	783
Urine N, gms	9.85	7.98	8.91
I.W.	1250	1037	1144
Fe.W.	53	46	50
Ur.W.	577	451	514
Wox.	362	300	331
B.W.	682	398	540
Min. Ur.W.	575	448	512
Min. W. I., observed	835	830	832
IW = 1000	585	793	689

TABLE 34

PARTITION OF BODY WEIGHT LOSS
DURING CONSUMPTION OF USAF-EMERGENCY RATION: DEVELOPMENTAL NO. 2
ROOM TEMPERATURE +22°C ±2°C., RH: 50-60%

(Daily Averages Values for the 4th Through the 6th Days)

Subject	D.A.	H.H.
Total Caloric Output	2748	2297
Weighted Av. RQ	0.88	0.88
Weighted Av. Cal/LO_2	4.85	4.90
Av. Urine N, gms	9.85	7.98
Total O_2 Consumption, L	566	469
Total CO_2 Production, L	499	413
Metabolic Mixture		
CHO, gms	391	325
PRO, gms	62	50
FAT, gms	106	88
Body Tissue Loss, gms.	106	20
Fecal Solids, gms.	22	26
Body Water Loss, gms.	682	398
Calculated Weight Loss, gms.	810	444
Weight Loss, Observed, gms.	833	456

C. EXPERIMENTS WITH USAF EMERGENCY RATION, DEVELOPMENTAL NO. 2

2. Alaskan Field Trial

The second developmental emergency ration was evaluated under field conditions of the arctic environment (Ladd Field, Alaska) according to the criteria of acceptability, nutritional adequacy and field utility. This study has been reported in detail elsewhere (27) and will be summarized briefly below.

Four groups of five men each served as subjects, each group subsisting on a different ration. Group I was a control representing a normal diet and subsisted on Combat Ration, Type E, modified to provide approximately 3500 calories. Group II ate the second developmental USAF emergency ration (2140 calories). Group III served as a control representing current issue; the men in this group ate one unit of Parachute Emergency Ration per day which made available about 1000 calories. The fourth group fasted and thus provided a negative control to this ration appraisal. A restriction in water intake of 800 cc. per day was also imposed.

The data obtained on the four groups of subjects are summarized in Table 35. The high osmolar concentrations deserve comment. The values obtained by the freezing point technique used are probably in error. The errors arising from diluting the urines and supercooling would give false high osmolar concentrations (see results of Preliminary Studies). To define the Min. Ur. W. and Min. W. I. for these data on the basis of Gamble's factor for maximum osmolar concentration, 1.40, would give faulty estimations.

It is to be noted that the average daily weight losses were proportional to the caloric deficit. Total urine nitrogen, solutes and urine water were approximately the same for the group eating the developmental emergency ration as for the fasting group. The values for these measurements were significantly more favorable in the group consuming the Parachute Emergency Ration. However, failure to eat the entire ration (P.E.R.), especially the cheese-cracker bar and bouillon cube, materially reduced the nitrogen and salt intake. This was reflected in a much greater negative nitrogen balance, but also a lower value for urine nitrogen, solutes, and urine water.

There was no increase in blood non-protein nitrogen. Plasma protein values were within normal limits and showed no siginficant change. The fasting group was the only one to manifest any evidence of hemoconcentration as measured by the hematocrit and hemoglobin concentrations. The results of the Harvard Step Test are interpreted to indicate a significant deterioration in physical capacity in the fasting subjects, but no significant alteration in the subjects of the other groups.

The conclusions drawn from the field trial were as follows:

1. The field utility and general acceptability of the second developmental emergency ration are satisfactory but several minor improvements are indicated. Men eating this ration had strikingly more initiative in improving their lot and less discomfort from the cold than either the fasting subjects or the men eating the Parachute Emergency Ration.

2. Parachute Emergency Ration is wholly unsatisfactory regarding acceptability and maintenance of morale but, if eaten, favors water balance as compared with fasting. Physical capacity was maintained for the period of this test.

3. A free fluid intake of 800 cc. per day appeared to be adequate to maintain physiological water balance during consumption of either of the emergency rations. The quantity was probably inadequate for the fasting subjects as reflected in the hemoconcentration.

TABLE 35

ALASKAN FIELD TRIAL OF EMERGENCY RATIONS[1]

(Daily Average Values for the 4th Through the 6th Days)

	Group I	Group II	Group III	Group IV
Diet, Calories	3498	2146	803	0
N, gms.	23.0	8.1	2.4	0
Caloric Output[2]	3060	2830	2460	2400
Weight Loss, gms.	150	426	666	942
%	3.3	5.5	7.6	8.1
Water Intake[3], cc.	1920	848	815	800
Urine:				
Volume, cc.	1087	587	475	603
Nitrogen, gms.	12.51	8.67	6.36	8.50
Sp. Gr.	1.030	1.034	1.032	1.029
Solutes, m-osM	1514	928	730	880
Osmolar Conc., osM/L	1.36	1.58	1.54	1.46
Ur.W.	1035	555	450	574
Blood				
NPN, mg %, Initial	32	32	27	30
Final	27	29	23	30
Plasma Protein, gms %				
Initial	6.8	7.1	6.9	6.9
Final	6.1	6.6	6.5	6.2
Hematocrit, %, Initial	48	46	48	46
Final	47	45	49	51
Hemoglobin, gms, Initial	16.2	15.8	15.9	16.0
Final	15.2	14.8	16.1	17.7
Step Test, Initial	0.56	0.80	0.50	0.59
Final	0.62	0.69	0.44	0.35
Change, %	+8	-15	-12	-40

1. Fasting studies terminated after 6th day because of hemoconcentration.
2. Estimated fr[illegible] time-activity data and standard metabolic cost tables.
3. Includes preformed water of ration.

D. PRELIMINARY STUDIES

1. Experiment with USAF Emergency Ration, Developmental No. 3

The data obtained from a single subject during consumption of the third developmental emergency ration (USAF-ER-3) and a restricted water intake while residing continously in the constant temperature room (+22°C ±2°C., RH: 50-60%) for 7 days are summarized in Tables 36-39. This ration was made up of components used in the second developmental ration (USAF-ER-2) with the addition of 10 gms. of heat coagulated egg white to provide the desired nutrient composition. The ration was studied for its effects upon water balance and not for its acceptability. It served as an experimental diet with no intention of recommending it for an emergency ration in the form used.

The cumulative loss of body weight represented 8.35 per cent. The difference between WI and Ur.Vol. during the first three days of recovery is much greater than that encountered in the last 3 days of the control phase. This increased difference implies a physiological need for water as the body retains more of the water intake. As mentioned previously such an interpretation is lacking in proof. The lower urinary volume in the recovery period may also be the result of salt retention as indicated by the relatively low urinary chloride excretion. The level of urine chloride during the experimental phase deserves comment. The essential difference in rations number 2 and number 3 with respect to salt content is the absence of bouillon from the latter. The single bouillon cube in ration number 2 provides approximately 2.0 gms. of sodium chloride. This probably explains the higher level of urinary chloride excretion and total solute output observed with developmental ration number 2.

Data obtained on the same subject (JR) during consumption of 2 Parachutes Emergency Rations (P.E.R.) per day are presented in Table 40, to provide a basis for comparison of the observations made upon ration 3. The experiment with the Parachute Emergency Ration was a preliminary study to provide experience for the technicians.

The urinary nitrogen loss for USAF-ER-3 is appreciably greater than that observed with P.E.R. This may reflect the influence of caloric deficit upon the efficiency of nitrogen utilization. However, the total solute output for P.E.R. is greater which probably is the result of its higher salt content (2 bouillon cubes).

The negative nitrogen balance, -2.81 gms. represents the daily catabolism of approximately 18 gms. of body protein during the first 6 days. The rise in hematocrit and hemoglobin concentration are interpreted as indices of hemoconcentration.

The respiratory exchange data from which total caloric expenditures were computed are given in Table 37. The average daily caloric output was approximately 2100 calories, or 2400 calories when expressed in terms of the standard 70 Kg. man.

TABLE 36

CHANGES IN CLINICAL LABORATORY DATA DURING CONSUMPTION OF USAF-EMERGENCY RATION, DEVELOPMENTAL NO. 3
ROOM TEMPERATURE +22° ±2°C.
RH: 50-60%

Subject: J.R.

	Control[1] Phase	Experimental[2] Phase	Recovery[3] Phase
Body Weight[4], Kg	61.832	56.668	59.512
Diet, Calories	2938	1023	3057
CHO, gms	449	92	470
PRO, gms N	15.89	6.4	12.48
FAT, gms	75	55	87
Water Intake, cc.	1500	800	1500
Caloric Output	2274	2120	2200
Urine			
Volume, cc.	1262	483	808
Nitrogen, gms	10.98	9.29	10.94
Sp. Gr.	1.019	1.023	1.027
Solutes, m-osM	1007	664	1060
Osmolar Conc., osM/L	0.80	1.38	1.27
Chloride, gms, as Na Cl	9.76	2.51	6.72
Blood			
NPN, mg %	38	41	33
Chloride, mg %, as Na Cl	410	430	450
Sugar, mg %	98	90	89
Hematocrit[4], %	47	51	44
Hemoglobin[4], gms	15.5	17.4	16.4
RBC[4], x 10^6	5.25	5.52	5.67

1. Daily average values for the last 3 days.
2. Daily average values for the 4th through the 6th days.
3. Daily average values for the first 3 days.
4. Values for last day of control and experimental phases, 3rd day of recovery.

TABLE 37

SUMMARY OF RESPIRATORY EXCHANGE DATA
DURING CONSUMPTION OF USAF-EMERGENCY RATION, DEVELOPMENTAL NO. 3
ROOM TEMPERATURE +22° ±2°C., RH: 50-60%

(Daily Averages for the 4th Through the 6th Days)

Subject: J.R.

Activity	Time Hrs.	Cals/Hr.	RQ	PMV l/min.
Sleeping*	7.08	60	0.82	4.1
Lying	2.50	70	0.78	4.5
Reading	6.18	75	0.77	4.5
Sitting	0.17	95	0.80	6.6
Eating*	0.42	95	0.80	6.0
Writing	3.05	95	0.78	6.5
Cards	0.17	100	0.85	6.2
Walking	4.02	150	0.80	8.8
Treadmill	0.40	210	0.80	12.2

*Estimated

The components of the water exchange are summarized for the 4th through the 6th days of ration consumption in Table 38. The comments made on the relation of IW to BW in the presentation of results obtained in the room temperature study of ration No. 2 are applicable here. The daily changes in the components of the water exchange illustrate the adjustment to a restricted water intake:

Day	Av. Room Temp., °F	Water Intake B.W.	W.I.	Wox	Water Output Ur.W.	Fe.W.	I.W.	Wt. Loss
1	+75	1173	818	270	839	0	1422	1352
2	+80	812	818	231	563	198	1150	988
3	+84	520	818	244	478	0	1104	652
4	+79	689	818	250	426	0	1331	832
5	+75	466	818	250	465	0	1069	612
6	+70	286	818	254	485	0	873	436
7	+70	115	818	282	442	0	773	292

The body water loss is considerably higher during the first five days than that observed in the last 2 days when the mechanical difficulties in regulating the room temperature were overcome. The correlation of I.W. and B.W. is noteworthy. This explains the high average body water loss recorded in Table 38. It is the result of a large extra-renal water loss (I.W.) rather than the effect of the ration.

The average daily solute output in the urine was found to be 664 milliosmoles. This solute load defines a minimum urine water requirement of 450 cc. or 510 cc. for a 70 Kg. individual. In the presence of maximum osmolar concentration of 1.38, it is assumed that body water is not being withdrawn beyond the physiologically available quantity. The minimum water intake necessary to prevent dehydration was computed to be 808 cc. When re-calculated for an I.W. = 1000, the Min. W.I. is estimated to be 717 cc. or 810 cc. per 70 Kg. per day.

The data used to calculate the amount of body substance catabolized (metabolic mixture minus the ration) during consumption of the third developmental emergency ration are presented in Table 39. The calculated daily weight loss agrees well with the observed changes in body weight. The body tissue catabolized represents 22 per cent of the total weight loss; the body water loss during the 7 day period is estimated to be 9.4 per cent of the initial body water (70% of body weight). Physical examination of this subject revealed evidence of dehydration—parched and cracked lips, sunken eyeballs, dry mouth, marked decrease in tissue turgor, and obvious weight loss. It is interesting to note that the severity and complaint of thirst subsided during the last three days of the study.

TABLE 38

COMPONENTS OF THE WATER EXCHANGE
DURING CONSUMPTION OF USAF-EMERGENCY RATION, DEVELOPMENTAL NO. 3
ROOM TEMPERATURE +22° ±2°C., RH: 50-60%

(Daily Average Values for the 4th Through the 6th Day)

Subject: J.R.

Caloric Intake	1023
Caloric Deficit	1095
Water Intake*, cc.	818
Urine Volume, cc.	483
Urine Solutes, m-osM	664
Urine N, gms.	9.29
I.W.	1091
Fe.W.	0
Ur.W.	459
Wox	251
B.W.	480
Min. Ur. W.	450
Min. W.I., observed	808
I.W. = 1000	717

TABLE 39

PARTITION OF BODY WEIGHT LOSS
DURING CONSUMPTION OF USAF-EMERGENCY RATION, DEVELOPMENTAL NO. 3
ROOM TEMPERATURE +22° ±2°C., RH: 50-60%

(Daily Average Values For The 4th Through The 6th Days)

Subject: J.R.

Total Caloric Output	2120
Weighted Av. RQ	0.78
Weighted Av. Cal/LO_2	4.76
Av. Urine N, gms	9.29
Total O_2 Consumption, L.	455
Total CO_2 Production, L.	354
Metabolic Mixture	
CHO, gms	106
PRO, gms	58
FAT, gms	159
Body Tissue Loss, gms	136
Fecal Solids, gms	0
Body Water Loss, gms	480
Calculated Weight Loss, gms	616
Observed Weight Loss, gms	627

TABLE 40

CHANGES IN CLINICAL LABORATORY DATA
DURING CONSUMPTION OF PARACHUTE EMERGENCY RATION, TWO UNITS,
ROOM TEMPERATURES, RH: 60-80%

	Control[1] Phase	Experimental[2] Phase
Body Weight[3], Kg	62.729	59.837
Diet, Calories	3049	1973
CHO, gms		272
PRO, gms N	21.4	6.25
FAT, gms		76
Water Intake[4], cc.	2500	830
Caloric Output[5]	2560	2477
Urine		
Volume, cc.	1810	575
Nitrogen, gms.	16.0	7.58
Sp. Gr.	1.018	1.031
Solutes, m-osM	1341	774
Osmolar Conc., OsM/l.	0.79	1.37
Sugar, gms	0	3.8
Ur.W.		546
Min. Ur. W.		525
Min. W. I.[6]		779
Blood		
NPN	39	38
Hematocrit[3], %	48	48
Hemoglobin[3], gms	16.4	15.9
RBC[3], x 10^6	4.97	5.20

1. Average values for last 3 days.
2. Average values for the 4th through the 6th days.
3. Values for last day of control and experimental phases.
4. Includes proformed water content of P.E.R.
5. Estimated from metabolic cost tables.
6. Min. W.I. = Min. Ur.W. + (W.I. - Ur.W.).

D. PRELIMINARY STUDIES

2. Technique of the Freezing Point Determination on Urine*

When the project of appraising emergency rations was undertaken, it was considered essential that the experimental methods used should be the same as those used by the other investigators working concurrently on related studies. The technique of the freezing point determination was that recommended by Schwimmer and Drekter. A detailed description of the technique has been presented (Section V, Laboratory Methods). It became apparent as the experiments herein reported were compared with the results obtained by Schwimmer that he was getting lower osmolar concentrations and total solute loads. It was subsequently learned that these results were based upon freezing point determinations of undiluted urine in contrast to the diluted urine technique originally recommended. To evaluate the direction and magnitude of effect of diluation, supercooling, and other factors upon the ΔT_f of urine, the preliminary study which follows was initiated:

Theoretical considerations suggest errors may be introduced in the determination of the freezing point by four factors:

1. Changes in osmotic activity as the result of dilution.

2. Precipitation of solutes due to temperature-solubility relationships.

3. Concentration of the solution due to excessive ice formation (supercooling, etc.).

4. Intrinsic errors of technique - rate and amplitude of stirring, reading the thermometer, etc.

The purpose of the freezing point determination on urine in these studies is to measure its osmolarity and the solute load. The freezing point of a solution is defined as the temperature at which the solid and liquid forms exist together in equilibrium. When a dilute solution of a solute in a solvent is cooled, the solid solvent begins to separate from solution. At the freezing point all three phases, solid, liquid and vapor, are in equilibrium. Solutions freeze at lower temperatures than the pure solvent, provided the solid phase is the same in both cases. The freezing point lowering (ΔT_f) of a solution is the result of the vapor pressure lowering of the solvent by dissolved solute. The magnitude of ΔT_f for a solution depends upon the nature of the solvent and the concentration of the solution. The freezing point depression varies linearly with concentration irrespective of the nature of the solute (not ionized) for dilute solutions of various solutes. This relationship has been expressed mathematically:

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*The freezing point determinations of this preliminary study were performed by Capt. George Mellinger, MC (USAF).

$$\Delta T_f = K_f m$$

K_f = Proportionality constant of concentration variation.
M = Molality of the solute.

The molal freezing point lowering constant (K_f) depends upon the nature of the solvent, not the concentration or nature of the solute. This value is 1.858°C/mole/1000 grams water. Because of the assumptions made in the derivation of the above equation, its application is valid only in dilute solutions. Deviation from this constant increases with concentration of the solution.

From the standpoint of a physical chemical determination, the above considerations indicate that the measurement of ΔT_f should be made on diluted urine. However, this procedure is used in these studies as an index of the osmolarity of the urine as the kidney actually secretes it. The osmotic work imposed upon the kidney is measured by the sum of the molecules and ions in the urine as reflected in the ΔT_f. The kidney can remove a given solute load with less osmotic work by eliminating more undissociated molecules and fewer ions in a concentrated urine than in dilute urine. Thus, from the standpoint of a physiological measurement, the ΔT_f should be determined on undiluted urine.

Diluting the urine for a ΔT_f determination has two effects: (1) reduces the error from precipitation of solutes due to the temperature-solubility factor, and (2) increases the osmotic activity of the solutes by a dilution dissociation of complex molecules. In the case of some solutes, such as glucose, osmotic activity decreases with increasing dilution, while with others (eg, Na Cl) it increases with increasing dilution. The data obtained on 7 overnight speciments of urine are presented in Tables 41-42. To separate the effects of precipitation, dilution, and supercooling, the ΔT_f was determined under the following conditions:

1. Ice Bath -8°C. alcohol inner bath, supercooling 3-5°C.
   A. Undiluted urine
   B. Urine diluted 1:10

2. Ice Bath -4°C. inner bath of air, supercooling 0.5°C.
   C. Undiluted
   D. Undiluted supernatant, precipitation by refrigerated centrifugation.

3. Ice Bath -2°C. inner bath of air, supercooling 0.5°C.
   E. Urine diluted 1:10
   F. Supernatant urine diluted 1:10

The osmotic activity of the total solutes in these urine specimens increased with dilution. A dilution of 1:10 resulted in an average increase of 13% in osmolarity (range, 3-17%). Precipitation of solutes during the cooling prior to freezing removes certain substances from

the urine solution. The precipitated solutes are osmotically inactive at the time of the actual determination. This would tend to make the values as determined somewhat lower than the true ΔT_f. Such an effect would be considerably reduced or negligible in diluted urine. In the 7 overnight speciments of urine, it was found that an average of 2.7 per cent (range, 0-6%) of the solutes were precipitated with the result that the determined values for osmolar concentration were low by that amount.

Concentration of the urine due to ice formation during the determination introduces a considerable error by causing the liquid phase to be more concentrated at the end point of the determination. Though this error cannot be entirely prevented, it should be minimized as much as possible. Excessive supercooling of the urine (by allowing spontaneous freezing) should be avoided by the addition of a small crystal of ice to initiate crystallization. Too rapid transfer of heat from the urine to the ice bath causes excessive ice formation during the time required for equilibrium to be reached. Too low a temperature in the ice bath, or a liquid such as alcohol in the inner bath, contribute to this error. In addition, when sufficient ice has been formed, a direct ice bridge will form between the thermometer and the inner glass chamber. Heat can be conducted directly by such a bridge and cause the thermometer to read too low. This introduces an unknown amount of error but can be eliminated with attention to the amplitude of stirring.

The combination of the above factors (ice bath -8°C., supercooling 3-5°C., and an alcohol inner bath) caused an average error of +9 per cent (range, 6-10%) and +11 per cent (range 3-17%) in undiluted and diluted urines respectively.

The amount of supercooling should be reduced to a minimum compatible with the formation of sufficient ice to keep the liquid phase in equilibrium with the solid phase. About 0.4° to 0.5°C. supercooling has proven to be a satisfactory maximum amount. The ice bath should be 1-2°C. below the freezing point (F.P.) of the urine. Differences of less than 1°C. may be found to be insufficient since the heat coming in from the outside may more than counterbalance the transfer of heat from the solution to the ice bath, causing the ice which may have formed to disappear. If the ice bath is more than 2°C. below the F.P., heat transfer will be too rapid and excessive ice formation and concentration of the urine will result. Using such an ice bath (1-2°C. below the F.P.) will be found to cool the solution only very slowly so that the procedure would be too time consuming. To obviate this difficulty, a separate ice bath with a temperature of -8° to -10°C. should be utilized for the cooling prior to the actual determination. The entire apparatus including the solution are immersed in this second ice bath until the temperature of the urine is about 0.2 -0.3°C. below the freezing point, and then transferred to the other ice bath. The temperature of the urine will continue to drop for a short time but usually levels off at about 0.4°C. below the F.P. The ice crystal is then added.

Intrinsic errors of reading the thermometer and other uncontrolled factors can be reduced by using undiluted as opposed to diluted urine. A given error will be a much smaller percentage of the freezing point

of undiluted urine. In reference to Table 42, it will be noted that an average error of +25 per cent (28% minus 3% for prevention of ppt.) was obtained from the combination of factors (supercooling and dilution) that influenced the measurements made according to the technique employed (see laboratory methods) throughout the studies herein reported. That such an error is involved in these data is unfortunate. However, the direction of the error is such that the "true" results would be more favorable to the rations studied than the data presented would indicate. The quantitative magnitude of this combination of errors requires further study since it may vary with the nature of the solutes (eg, fasting).

In summary, the following precautions should be observed in the freezing point determination of urine:

1. The urine should be supercooled no more than about 0.4°-0.5° below the F.P. of the urine, and should always be to as nearly the same amount as practical.

2. The ice bath should be 1°-2° below the F.P.

3. A second ice bath with a temperature of about minus 8°-10°C. should be used to expedite cooling the urine to about 0.2°-0.3°C. below the F.P. before placing the apparatus in the other bath.

4. The inner bath should be filled with air rather than a liquid.

5. Undiluted urine should probably be used when the ΔT_f is to serve as a measure of osmotic work performed by the kidney. How much error is thus introduced by deviation of K_f from the constant value, 1.86, is unknown. In the samples examined, the error introduced by dilution outweighed any advantage due to prevention of precipitation by means of dilution. This may not be true of more concentrated urines. If greater accuracy is desired, the effect of precipitation can be estimated by determining the F.P. of dilutions of the urine before and after precipitation (refrigerated centrifugation).

6. The rate and amplitude of stirring and other variable factors in technique should be kept as constant as is practical.

TABLE 41

EFFECTS OF PRECIPITATION, DILUTION AND SUPERCOOLING UPON THE FREEZING POINT DETERMINATION ON URINE

(Values Represent Osmolar Concentrations, osM/L)

Specimen	Sp. Gr.	Ice Bath - 8°C. Alcohol Bath Supercooling 3°— 5°C.		Ice Bath - 4°C. Air Bath Supercooling 0.5°C.		Ice Bath - 2°C. Air Bath Supercooling 0.5°C.	
		Undiluted A	1:10 Dilution B	Undiluted C	Undiluted Supernatant D	1:10 Dilution E	1:10 Dilution of Supernatant F
G.W.M. -1	1.032	1.34	1.49	1.23	—	1.28	—
G.W.M. -2	1.027	—	—	—	0.816	0.957	0.908
J.L.D.R.	1.032	—	—	—	1.09	1.18	1.18
G.W.M. -3	1.031	1.18	1.41	1.11	1.11	1.30	1.24
H.F.H.	1.029	1.12	1.37	1.02	1.02	1.18	1.18
H.P.	1.023	0.89	1.01	0.82	0.82	0.978	0.962
D.L.	1.022	0.905	1.19	0.848	0.848	1.02	0.962
M.M.J.	1.018	0.578	0.618	0.502	0.496	0.586	0.575

Supernatant obtained from urine cooled to -3.5°C. and centrifuged at 3000 RPM at 0°C. for 15 minutes.

TABLE 42

EFFECTS OF PRECIPITATION, DILUTION AND SUPERCOOLING UPON THE FREEZING POINT DETERMINATION ON URINE

(Values represent % Change or Error)

Specimen	Supercooling Undiluted $\frac{A - C}{C} \times 100$	Supercooling Diluted $\frac{B - E}{E} \times 100$	Precipitation $\frac{F - E}{E} \times 100$	Dilution $\frac{F - D}{D} \times 100$	Error of Method $\frac{B - C}{C} \times 100$
G.W.M. -1	+8.9	+16.4	—	—	+21.1
G.W.M. -2	—	—	-5.1	+11.3	—
J.L.D.R.	—	—	0.0	+8.2	—
G.W.M. -3	+6.3	+8.5	-4.6	+11.7	+27.0
H.F.H.*	+9.8	+16.1	0.0	+15.7	+34.3
H.P.*	+8.8	+3.1	-1.6	+17.1	+23.2
D.L.+	+6.7	+16.7	-5.9	+13.5	+40.0
M.M.J.*	+15.1	+5.5	-1.9	+15.9	+23.1
Average	+9.3	+11.1	-2.7	+13.3	+28.0

*Slight to no ppt. on supercooling.
+Ppt. at room temperature; no more when cooled to -3.5°C.

VI. DISCUSSION

A. Appraisal of Emergency Rations

   1. Sparing of Body Tissue

   2. Preservation of Physical Capacity

   3. Maintenance of Morale

   4. Prevention of Ketosis

   5. Minimum Cost to Water Balance

      a. Physiological

      b. Mechanical

B. Role of Rations in Survival

   1. Clothing versus Food

   2. Water versus Food

DISUCSSION

A. Appraisal oi Emergency Rations

Acceptability, storage stability, nutritional adequacy and field utility are the major considerations in ration design and development. The importance of acceptability in formulating a ration cannot be too strongly emphasized. If a food item is not acceptable to a soldier under the circumstances for which it is intended and he discards it, then that ration has no nutritional value to him regardless of its chemical and biological assay values. If the ration takes the form of a food item which the soldier recognizes as such and is accustomed to eating, rather than a highly processed unnatural product, he is more likely to eat it and like it. Acceptability may be greatly reduced by deterioration changes accompanying storage, by deficiency in essential nutrients, by the presence of deleterious compounds which may occur naturally or as the result of processing, or by difficulties encountered in the preparation and consumption of the ration in the field. Indoctrination in the most advantageous use of rations and limited water supply in survival circumstances and instruction relative to the rationale for an almost pure carbohydrate ration, are essential to the acceptability of the components of the ration. If the ration is to be used under survival circumstances, caloric density is a factor of considerable importance in order to meet the restricted space and weight allowances aboard aircraft. The nutritional adequacy of a survival ration is evaluated according to the following criteria:

1. Cost to water balance

    a. Mechanical - displacement of water provision by a larger ration

    b. Physiological - Min. Ur. N., B.W., Wox.

2. Prevention of ketosis

3. Maintenance of morale

4. Preservation of physical capacity

5. Sparing of body tissue

These factors are listed in a sequence approximating relative importance. They will be discussed in reverse order.

We are interested in knowing whether body tissue can be spared as a result of eating a ration without increasing urine nitrogen and thereby the renal water requirement. Data obtained by Gamble for various quantities of a pure carbohydrate ration serve as a basis of comparison (9). In Figure 11 protein sparing is calculated from the negative nitrogen balance data and the values are expressed as body protein loss in percent of the fasting level for the same subject; i.e., if 100 grams

of body protein were catabolized during fasting, only 59 grams were consumed when 100 grams of glucose were fed. When the glucose intake was raised to 200 grams, the urine nitrogen, which reflects body protein loss, was 49 per cent of the fasting level. Gamble observed no further lowering of urine nitrogen by increasing the intake of glucose to 300 grams and concluded that "The maximal protein sparing effect of glucose in conjunction with a deficient caloric intake is approximately 50 per cent of the loss of body protein incidental to the state of fasting." When 43 grams of protein, as egg white or casein, were ingested along with 100 grams of glucose, the body protein loss was reduced to 56 per cent, but at the expense of increasing urine nitrogen to 106 per cent of the fasting level. The oxidation of nearly all of the intake protein thus raised the urine nitrogen excretion to a value slightly above that for fasting. On the basis that this protein was being used for calories because of the large caloric deficit, attention was directed in the present studies to rations providing more non-protein calories in the hope that greater protein sparing might be accomplished from the protein content of the ration. USAF emergency rations 1 and 2 (Figure 11, rations E and F) provided approximately 2000 calories derived from 40 or 50 grams of high quality protein, 55 or 75 grams of fat and the remainder from carbohydrate. With these rations body protein loss was reduced still further to only 16 per cent of the amount lost incidental to fasting. Accompanying the protein sparing, there was a reduction in urinary nitrogen to 84 per cent of the fasting level. Thus, protection of body protein has been accomplished by the ingestion of the experimental rations, (USAF-ER-1 and -2) without increasing urinary nitrogen loss, and thereby renal water requirement, above the fasting level. However, since the efficiency of protein utilization was not 100 per cent, and since some of the protein ingested was being oxidized for energy when a caloric deficit of 500 to 1000 calories was present, the quantity of urinary nitrogen was greater than that found during consumption of the pure carbohydrate rations (A, B, C, Figure 11). Also, the protein intake may have been in excess of the minimum needs for these particular subjects. The cumulative daily losses of body protein in the state of fasting and for the same two subjects during a period of emergency ration consumption (USAF-ER-1) are shown in Figure 12.

Apparently no more than 1000 calories are necessary to maintain physical capacity, as measured by the Harvard Step Test, for a period of 10 days under the cold environmental conditions of these studies. Data obtained in the Alaskan field trial (27) indicate a significant deterioration in physical capacity occurred in the fasting subjects. However, no significant change was observed in the subjects of the other groups, whether the daily ration provided 1000 calories (Parachute Emergency Ration), 2000 calories (USAF-ER-2) or 3500 calories (modified E ration). If, in an experiment in progress, 100 grams of carbohydrate (400 calories) proves to be adequate in preventing ketosis and physical deterioration when caloric expenditure is marked, a single "all-purpose" survival ration would then be available for all geographical areas.

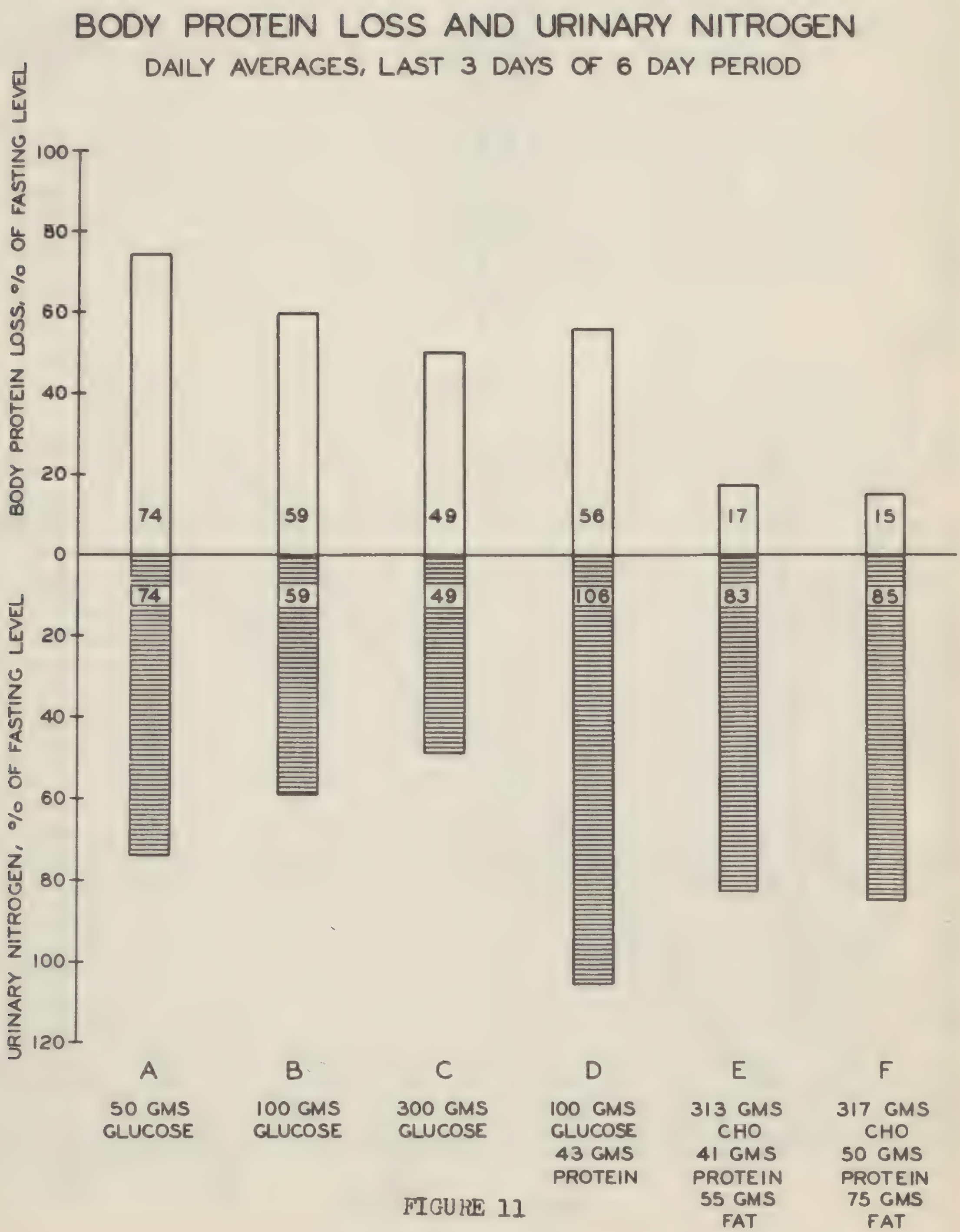
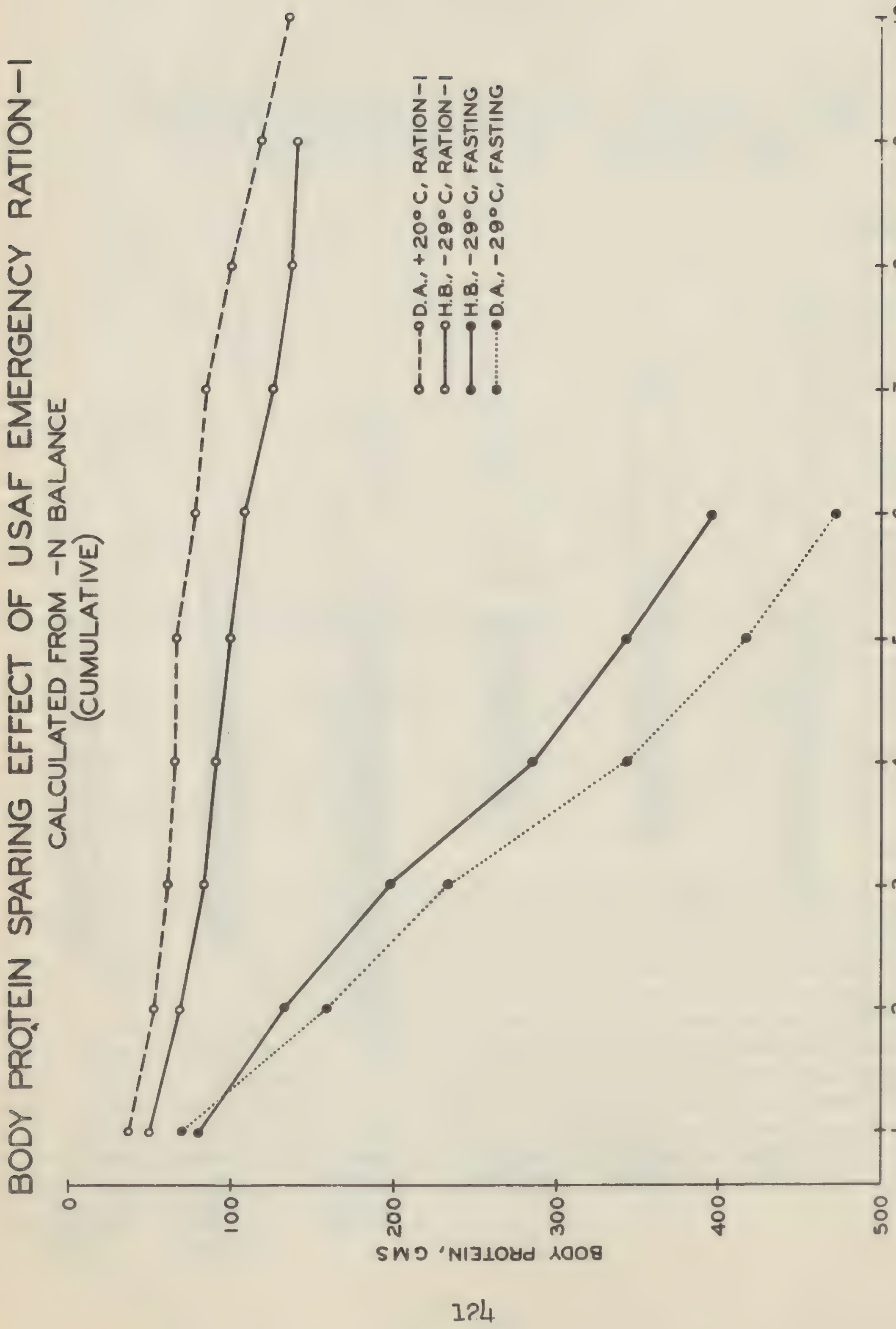

BODY PROTEIN LOSS AND URINARY NITROGEN
DAILY AVERAGES, LAST 3 DAYS OF 6 DAY PERIOD
BODY PROTEIN LOSS, % OF FASTING LEVEL
URINARY NITROGEN, % OF FASTING LEVEL
100
80
60
40
20
0
20
40
60
80
100
120
74
59
49
56
17
15
74
59
49
106
83
85
A
50 GMS GLUCOSE
B
100 GMS GLUCOSE
C
300 GMS GLUCOSE
D
100 GMS GLUCOSE 43 GMS PROTEIN
E
313 GMS CHO 41 GMS PROTEIN 55 GMS FAT
F
317 GMS CHO 50 GMS PROTEIN 75 GMS FAT

FIGURE 11

FIGURE 12



BODY PROTEIN SPARING EFFECT OF USAF EMERGENCY RATION-I
CALCULATED FROM -N BALANCE
(CUMULATIVE)
D.A., +20° C, RATION-I
H.B., -29° C, RATION-I
H.B., -29° C, FASTING
D.A., -29° C, FASTING
DAYS
1
2
3
4
5
6
7
8
9
10
BODY PROTEIN, GMS
0
100
200
300
400
500

Food may contribute physiologically and/or psychologically to the maintenance of morale. Gamble (5) noted cheerfulness and a sense of physical effectiveness in the subjects given glucose, which was in striking contrast to the unhappy lassitude of fasting. It is generally agreed that food may influence the kind of decision which the castaway makes. Many a castaway on a raft has hastened the end by resorting to large quantities of sea water as a means of assuaging thirst. Many a survivor on land has hastened the end by the unwise decision to travel in the height of the sun. Thus, the effect of the ration upon water balance may either favor or impair judgement. Food helps to bolster courage. The chance for survival depend to a great extent upon control of one's fear, or conversely, bravado.

No significant deterioration in morale was observed in the present group of studies. However, the men eating the rations on the Alaskan Field Trial had strikingly more initiative in improving their lot and less discomfort from the cold than the fasting subjects. It will be of interest to know whether or not 100 grams of carbohydrate is sufficient to maintain morale, as well as physical capacity, when there is a marked caloric expenditure as might be required in the arctic environment.

A survival ration must prevent ketosis in order that it may also preserve physical capacity, maintain morale, and have a minimum urinary water requirement. There has been considerable discussion of the eligibility of pemmican as a survival ration. Pemmican consists of dried meat and fat in approximately equal proportions by weight. Claims have been made that the best diet for the Arctic consists principally or even solely of animal fat and flesh. Despite the tradition of its successful use by explorers, it has not been issued to troops because it is unpalatable and not acceptable to the average individual. A field study of pemmican led Johnson (28) to conclude several points of general interest: "the overwhelming importance of acceptability in packaged rations; the dramatic suddenness and extent to which nutritional difficulties can develop in a few days; and the manner in which historical errors can be perpetuated. A platoon of infantry, well trained and acclimatized during maneuvers under subarctic conditions, received a ration consisting solely of pemmican and tea. They found it unacceptable, ate only about 1500 calories a day when they were expending about 4500, and within 3 days were tactically useless, showing exceedingly poor physical fitness, ketonuria, ketonemia, hypochloremia, and dehydration. The same pemmican proved acceptable when supplemented with biscuits, oatmeal, salt and sugar. During the next five days the men recovered most of their tactical effectiveness. A search of the literature revealed that insofar as published accounts will allow a semiquantitative estimate, no exploring party either in the Arctic or Antarctic has ever thrived on pemmican without carbohydrate supplement; and in fact, when very high percentages of pemmican have been included, sickness or disaster has been the lot of expedition." The failure of pemmican in this field study can in part be attributed to the ketogenic proportions of its nutrients.

All of the developmental USAF emergency rations of the present study have a high carbohydrate content and no evidence of ketosis was encountered. Gamble has shown that 100 grams of carbohydrate per day will prevent the development of ketosis when the caloric expenditure is barely above basal requirements; i.e., approximately 2000 calories per day. But will this same amount of carbohydrate prevent ketosis where a caloric expenditure or 4500 calories per day derives a greater proportion of fuel needs from stored body fat? There is a good chance that it will be adequate in view of the demonstration that severe exercise does not increase the degree of ketonuria (29).

The advantages of a survival ration must be appraised in terms of its cost to water balance, if there is a limitation in the space and weight allowances aboard aircraft for both food and water. Since thirsting is fatal much sooner than fasting and since castaways frequently can obtain only a limited water supply, the most important criterion for evaluating a survival ration is its effect upon water balance. A ration may influence water exchange through its obligatory renal water requirement, through its expenditure of body water, and through its water of oxidation (Chart 4). However, mechanical displacement of water provision by a larger ration may be of greater importance quantitatively than these physiological effects.

The minimum physiological expenditure of water by the kidneys depends upon the composition and quantity of solutes claiming removal from blood plasma. The nature and quantity of the solute load presented to kidneys is determined by the caloric output and dietary intake. The data related to Min. Ur. W. requirement are summarized in Table 43. The measurement of total urine solutes during fasting contains the end products of oxidation of body protein, the inorganic electrolytes removed with body water, and the abnormal solutes which accompany the ketosis of fasting. The increased output of ketone acids and increased production of ammonia result in a larger total solute load, and thereby a larger renal water requirement for the fasting state (Figures 13, 14).

The water of oxidation from an intake of glucose will not appreciably contribute to the water exchange (+14 cc/100 grams. glucose). However, Gamble has shown the more important effect of glucose to be the large reduction of the quantity of solutes claiming removal by the kidneys. The protein sparing effect of glucose accounts for part of this reduction of solute output (nitrogen and the intracellular electrolytes, K^+ and $HPO_4^=$). An unexpected finding during the glucose period was a marked conservation of the extracellular electrolytes, Na^+ and Cl (9). The absence of abnormal solutes as a result of the anti-ketogenic effect of glucose accounted for thirty-eight per cent of the total reduction in solute output in Gamble's subject. Renal water requirement was correspondingly reduced. Figure 15 illustrates the minimum urine water and urine nitrogen during periods of ration consumption, with values expressed as per cent of the fasting level. The estimation of Min. Ur. W. was reduced to 47 per cent of the fasting quantity when 100 grams of

SUMMARY OF DATA RELATED TO MIN. UR. W. REQUIREMENT

(Av. Daily Values For The 4th - 6th Days)

	GAMBLE'S DATA				A.M.L. DATA				
Environment	Rm.T.	Rm.T.	Rm.T.	Rm.T.	-29°C.	-29°C.	Rm.T.	+20°C.	+20°C.
Ration	Fasting	Fasting			Fasting	ER-1	ER-1	ER-2	ER-3
CHO, gms.	0	0	107	100	0	313	318	316	92
PRO, gms.	0	0	0	43	0	40.7	41.6	50.4	40
FAT, gms.	0	0	0	0	0	56	57	76	55
Cal. Intake	0	0	428	572	0	1912	1948	2140	1023
Cal. Output*	2000	2000	2000	2000	3150	2748	3108	2522	2118
Cal. Deficit	2000	2000	1600	1400	3150	836	1160	382	1095
Nitrogen Intake, gms.	0	0	0	6.88	0	6.51	6.66	8.06	6.40
Urine Nitrogen, gms.	12.6	11.1	7.32	12.80	10.12	9.16	8.19	8.91	9.29
Nitrogen Balance, gms.	-12.6	-11.1	- 7.32	-6.02	-10.12	-2.50	-1.53	-0.85	-2.89
Urine Solutes, m-osM	807	758	397	775	871	779	702	783	644
Osmolar Conc., OsM/1	0.93	1.35	0.46	1.17	1.29	1.39	1.32	1.44	1.38
Water Intake	1220	0	1220	1160	1000	907	830	835	818
Urine Water	994	531	841	636	644	539	507	514	459
Min. Ur. W.	558	503	262	530	597	516	480	512	450

Rm.T. = Ordinary Room Temperature

* = Approximate for Gamble's data

INFLUENCE OF A RATION ON WATER EXCHANGE

GAIN

1. Anti-ketogenic effect: reduction in organic acids and their ammonium salts requiring elimination.

2. Protein-sparing effect: reduction in catabolic N and intra-cellular K^+ and HPO_4 requiring urinary elimination.

3. "Sodium-sparing" effect: reduces ECW loss, mechanism unknown (? secondary to reduction in ECW loss resulting from 1 and 2).

4. Influence on I.W. (?): prevents acidotic hyperventilation and peripheral vasodilation.

5. Wox from CHO: is greater (+14 cc/100 gm. CHO) than from its caloric equivalent in body fat.

LOSS

1. Increase in urine ketone bodies resulting from excessive fat in ration, (ketogenic).

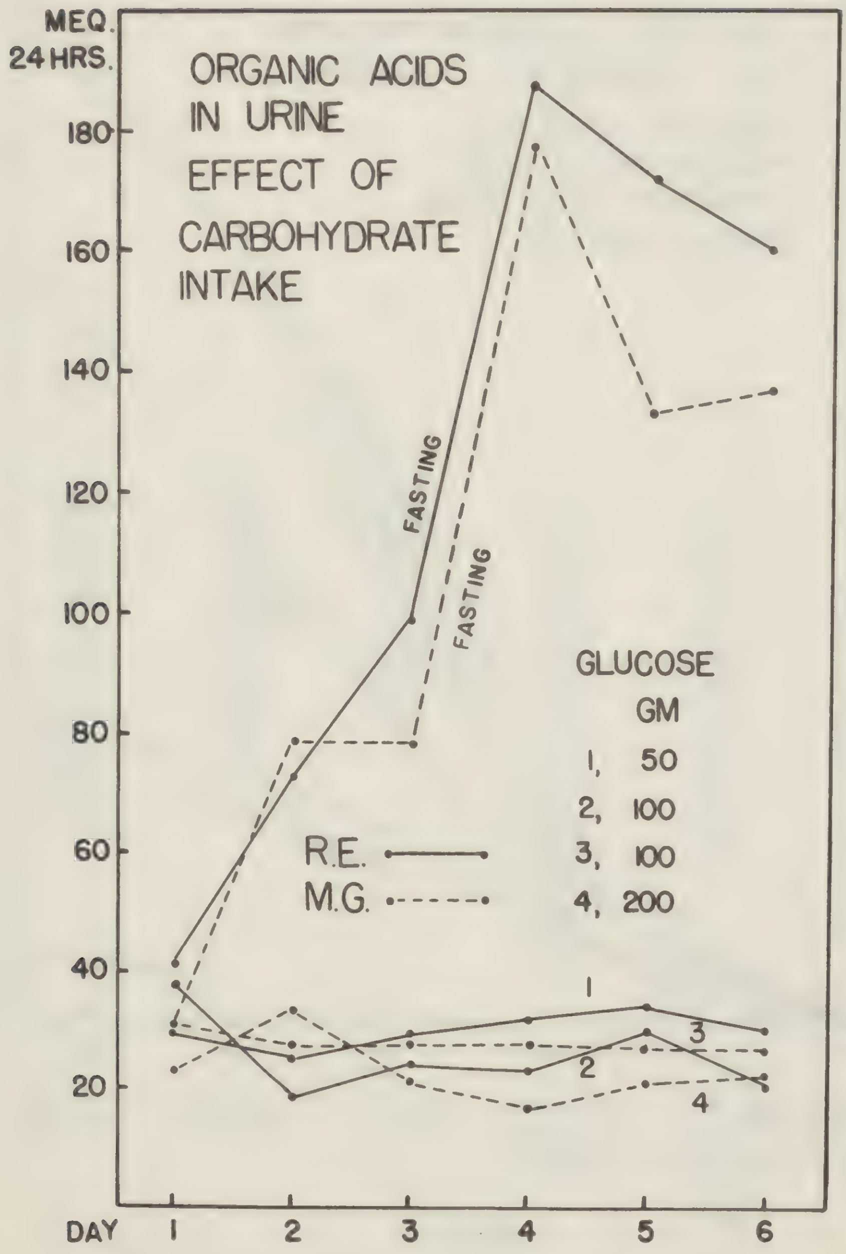
2. Increase in urine N: if dietary protein is of poor quality and/or utilized solely for calories (4.7 cc. per gm. protein).
   Protein sparing: reduces ICW available to the kidneys (3.2 cc/gm. protein).

3. Increase in urine electrolytes: if ration contains salts in excess of losses found for fasting (or when glucose alone is provided).

4. Body fat sparing: prevents release of ICW from fatty tissue (10 cc/100 gms fatty tissue).

5. Wox from Protein: is less (-7 cc/100 gms protein) than from its caloric equivalent in body fat.

FIGURE 13



4881-H-AML

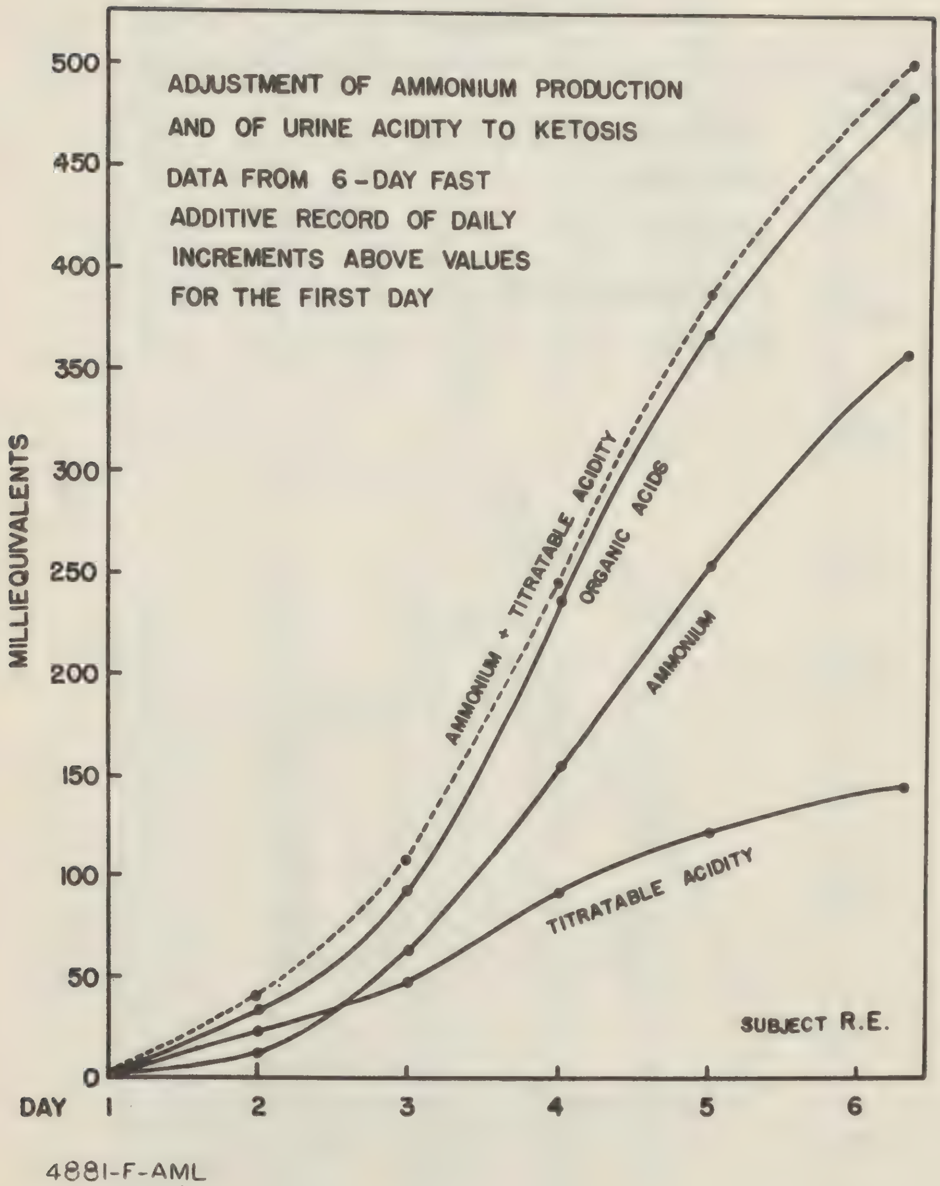

ADJUSTMENT OF AMMONIUM PRODUCTION
AND OF URINE ACIDITY TO KETOSIS
DATA FROM 6-DAY FAST
ADDITIVE RECORD OF DAILY
INCREMENTS ABOVE VALUES
FOR THE FIRST DAY
MILLIEQUIVALENTS
0
50
100
150
200
250
300
350
400
450
500
DAY
1
2
3
4
5
6
AMMONIUM + TITRATABLE ACIDITY
ORGANIC ACIDS
AMMONIUM
TITRATABLE ACIDITY
SUBJECT R.E.
4881-F-AML

FIGURE 14

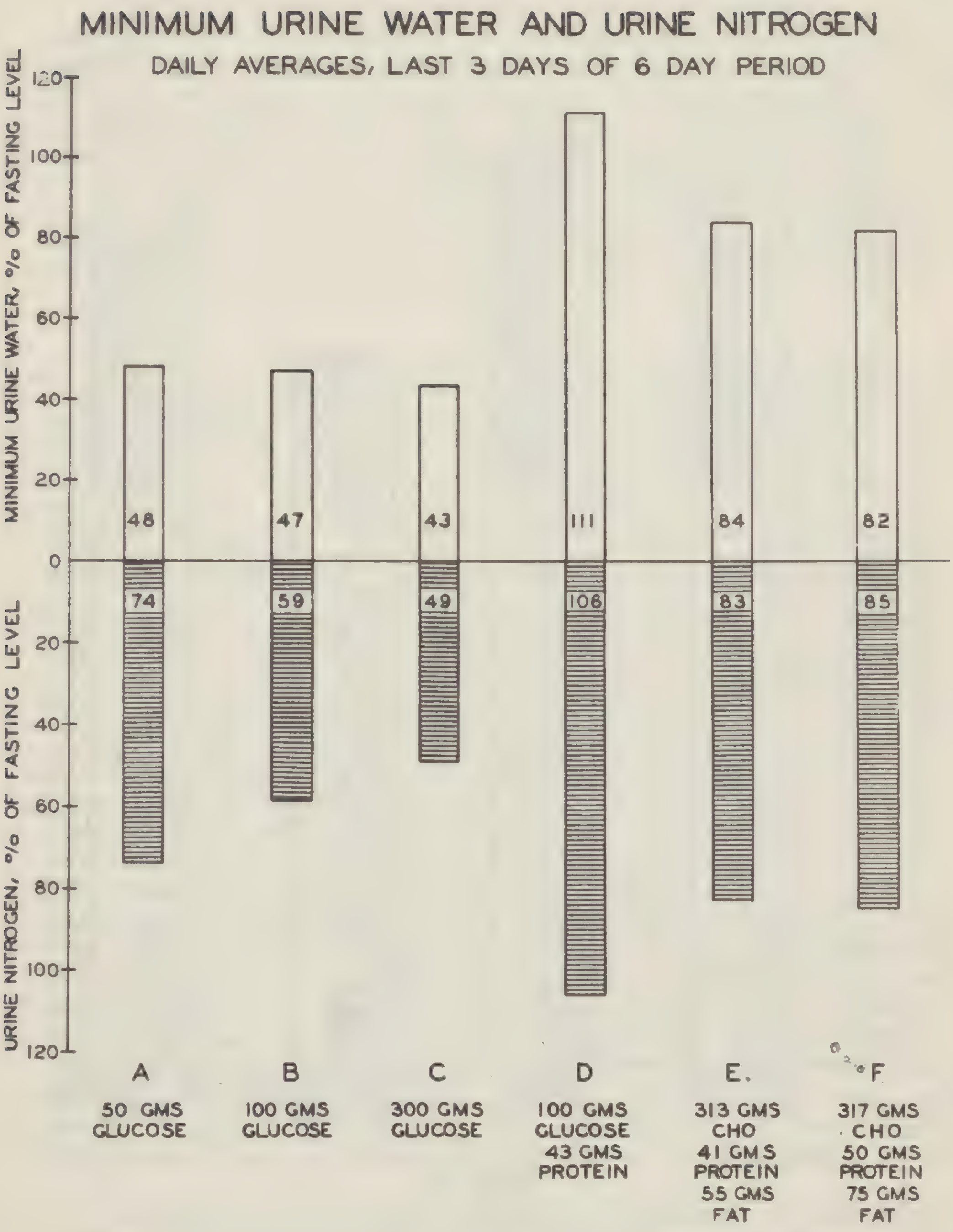
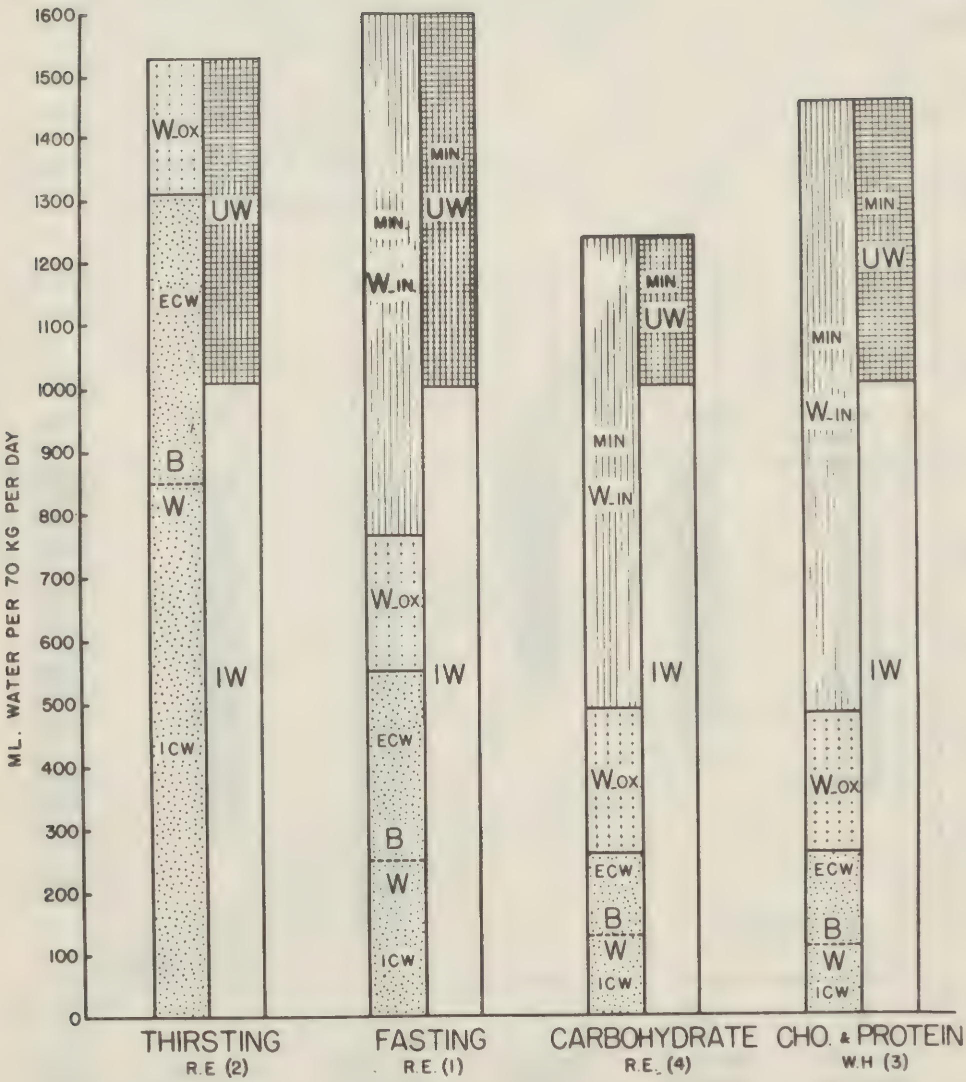

MINIMUM URINE WATER AND URINE NITROGEN
DAILY AVERAGES, LAST 3 DAYS OF 6 DAY PERIOD
MINIMUM URINE WATER, % OF FASTING LEVEL
URINE NITROGEN, % OF FASTING LEVEL
120
100
80
60
40
20
0
20
40
60
80
100
120
48
47
43
111
84
82
74
59
49
106
83
85
A
50 GMS GLUCOSE
B
100 GMS GLUCOSE
C
300 GMS GLUCOSE
D
100 GMS GLUCOSE 43 GMS PROTEIN
E.
313 GMS CHO 41 GMS PROTEIN 55 GMS FAT
F
317 GMS CHO 50 GMS PROTEIN 75 GMS FAT

FIGURE 15



4881-B-AML

FIGURE 16

COMPONENTS OF WATER EXCHANGE (GAMBLE'S DATA)

glucose were ingested. However, when 43 grams of protein were taken along with this amount of carbohydrate, the urine nitrogen was increased to 106 per cent of the fasting loss for the same subjects, and the obligatory renal water requirement was increased to 111 per cent. The oxidation of nearly all of the ration protein in the presence of a submaintenance caloric intake thus raised the urine nitrogen excretion and with it the urine water requirement.

In interpreting the data for osmolar concentration, total solutes and Min. Ur. W. obtained in the experiments with the various developmental USAF emergency rations, it is to be remembered that an error was present in the technique employed for determining the freezing point depression of the urine. However, the direction of error as a result of the effects of supercooling and dilution is such that the "true" results would be lower and thus more favorable to the rations studied than the data presented would indicate. Although preliminary studies revealed an error of +25 per cent, the quantitative magnitude of the error requires further study since it may vary with the concentration and nature of the solutes.

Despite this error, the results of the present studies show that a ration containing protein does not necessarily increase the solute load presented to the kidneys above that associated with fasting. Ingestion of the developmental USAF emergency rations (rations E and F, Figure 15) resulted in a moderate reduction of the Min. Ur. W. requirement to approximately 83 per cent of the fasting quantities, with corresponding reduction in the values for the urine nitrogen. Thus, if the source of dietary protein is of high quality, and if sufficient non-protein calories are available or the caloric deficit not too great, the protein content of a ration may be utilized to spare body protein in an amount beyond that of carbohydrate alone so that the urinary nitrogen level does not rise above that of fasting. The urinary nitrogen loss during consumption of a ration (USAF-ER-3) providing 1000 calories, 40 grams of protein and 55 grams of fat was appreciably greater than that observed with another ration (Parachute Emergency Ration) differing essentially in that the latter furnished approximately 2000 calories. This difference may be the result of the greater caloric deficit (1000 calories compared to 500) associated with the study of USAF-ER-3; i.e., more of the protein being utilized for calories. The results would have been more favorable had bouillon <u>not</u> been included in the rations. Despite the high order of acceptability and the favorable effect upon morale, bouillon does not appear eligible for inclusion in an emergency ration because of its high salt content. The sodium chloride, creatinine and other extractives present in a single bouillon cube are equivalent to an increase of 80 cc. in the renal water requirement. The low total solute output and Min. Ur. W. requirement for USAF-ER-3 illustrate the favorable effect of the absence of bouillon.

In Figure 16 are constructed the components of the water exchange from daily average values for the last three days of a 6 day

period of ration consumption. The fluctuations of the independent component, IW, were removed by construction the diagrams on the basis of a constant IW of 1000 cc. The values found for minimum water intake were adjusted to the difference between the observed values for IW and 1000 cc. This adjustment permits a demonstration of the relation between water intake requirement and the components of the water exchange which are directly altered by change in experimental conditions. Figure 16 and the discussion of it which follows are taken from a report of Gamble (9).

"The diagram for the fasting water exchange describes the extent of expendable body water which, together with water produced by oxidation of body fat and protein, covers nearly one-half of the total obligatory expenditure. Since this removal of body water is incidental to and parallels a loss of body substances, it is not a process of dehydration. Actual dehydration is produced when the added circumstance of thirsting compels withdrawal of body water beyond the physiologically available quantity. The difference in BW in the thirsting and fasting diagrams measures the extent of dehydration. The diagram for the carbohydrate experiment describes the extensive conservation of both extracellular and intracellular body fluids and the lowering of minimal water expenditure by the kidney with the net result that minimal water intake is less than is found for fasting. As shown by the last diagram, the addition of protein to an intake of carbohydrate does not appreciably alter the availability of body water but does make necessary a large extension of the renal water expenditure with corresponding increase of minimal water intake." The latter statement requires qualification; it applies to the circumstance of a marked caloric deficiency where the dietary protein is oxidized for fuel. However, if the protein intake replaces the consumption of body protein in an amount which is beyond the protein sparing effect of glucose, there should be no increase in the nitrogenous end products claiming removal in the urine and therefore no extension of the renal water requirement.

The reduction of available body water resulting from the sparing of body fat and body protein must also be considered in evaluating the effect of a ration upon water exchange. Intracellular water released with the consumption of body tissues is available to the kidneys for the elimination of waste solutes and its loss does not constitute dehydration. Intracellular fluid of sketelal muscle contains 3.2 grams water per 1.0 gram protein. Fatty tissue has been found by most investigators to be combined with 10 per cent of water. These factors were used in the calculations summarized in Table 44. To permit comparison of the estimations of body water expenditure and water requirement, a constant IW of 1000 cc. was assumed and adjustment made in the fat consumption for a constant caloric output of 2500 calories. Figure 17 illustrates the data diagramatically for the components of the water exchange. The observed values with actual variations in IW and caloric output are presented in the diagrams of Figure 18.

The protection of body protein observed in D.A. during consumption of USAF-ER-1 made available only 36 cc. of intracellular water in contrast to the 237 cc. released by the daily breakdown of 74 grams of tissue protein while fasting. Thus, the saving in minimum urine water requirement (703 - 575 = +128) is outweighed by the reduction of available I.C.W. (237 - 36 = -201). The net physiological effect of the ration upon water exchange is a daily deficit of 73 cc. compared to the fasting state. As will be pointed out later, this quantity of water would be of negligible significance with respect to survival expectancy. Examination of the figures for extracellular water expenditure indicates that the deficiency of I.C.W. has been compensated by an increased loss of E.C.W. during metabolism of the emergency ration (USAF-ER-2). The high E.C.W. loss results in a relatively low estimation of minimum water intake necessary to prevent dehydration (585 cc. compared to 843 for fasting). Since the extracellular water compartment can supplement the water intake to a limited extent and thus provide sufficient water for the solute load presented to the kidneys, the validity of the definition of Min. W.I. as used in these studies is questioned. An osmolar concentration of less than 1.40 is not a reliable indication that the kidneys are performing within the margin of safety for expendable body water. Measurable hemoconcentration is not sufficiently sensitive to reflect dehydration early, nor does it indicate redistribution of fluid within the extracellular compartment. Until there is a reliable and sensitive measurement of the "physiologically available quantity" of body water, perhaps the sum of the Min. $W.I._c$ + E.C.W. would give a better expression of the water requirement for a ration (calculated for a constant I.W. and constant caloric output). It is assumed that a portion of E.C.W. is expendable and would not lead to dehydration. However, to ignore that portion of E.C.W. which supplements the W.I. and assume it is indefinitely expendable might be misleading.

The calculations for the pure CHO and CHO + PRO experiments (Table 44) were adapted from data of Gamble. Although direct comparison is not possible because of the error in technique of the freezing point determination (data for D.D.) it is apparent that a pure carbohydrate ration reduces Min. Ur.W. more than it reduces available I.C.W. The net effect upon water exchange is a gain which Gamble has found to be about 140 cc. compared to fasting (5).

The quantitative importance of the mechanical displacement of water provision by a larger ration is demonstrated in the tabulation below:

	CHO	CHO + PRO	FASTING	USAF-ER-2
Min. $W.I._c$ + E.C.W.	796	1135	1157	1208
Wt. of ration, gms.	100	143	0	492
Total Weight, gms.	896	1278	1157	1700

The unique suitability of a pure carbohydrate ration from the standpoint of both physiological and mechanical cost to water balance is evident. The differences in water requirement for fasting for a carbohydrate + protein ration with greatly reduced caloric intake, and for the developmental USAF emergency rations are not significant. Thus, if the allowance for both food and water is limited, displacement of water provision by the weight of the emergency ration assigns greater importance to the mechanical factor than to the net physiological effect of the ration upon water exchange.

TABLE 44

COMPONENTS OF THE WATER EXCHANGE

(Calculated From a Constant I.W. and Caloric Output)

	Adapted From Gamble		D.A.	
Ration	CHO	CHO + PRO	Fasting	ER-2
Ration Composition				
CHO	100	100	0	317
PRO	0	43	0	50
FAT	0	0	0	75
Caloric Output	2500	2500	2500	2500
Metabolic Mixture				
CHO	100	100	Neg.	317
PRO	45	80	74	61
FAT	206	191	237	106
W.I.	1130	1160	1000	837
I.W.	873	1115	1142	1250
Ur. W.	841	636	718	577
Min. Ur. W.	262	571	703	575
Wox	299	296	283	328
I.C.W.				
W-PT	144	119	237	36
W-FT	23	21	26	3
B.W.	282	295	577	662
E.C.W. = B.W. - I.C.W.	115	155	314	623
$M.W.I._c$ (I.W. = 1000)	681	980	843	585
$M.W.I._c$ + E.C.W.	796	1135	1157	1208

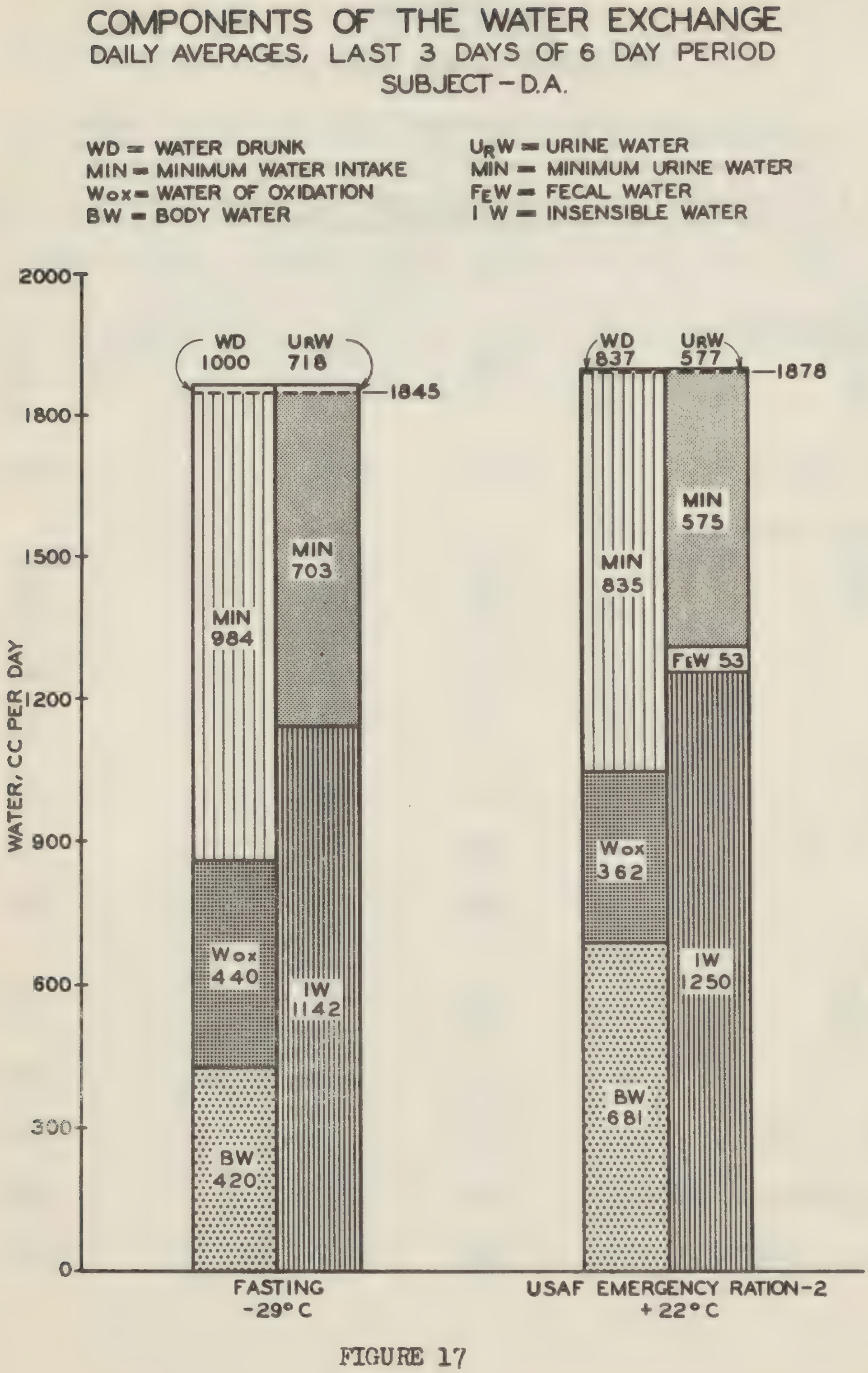

COMPONENTS OF THE WATER EXCHANGE
DAILY AVERAGES, LAST 3 DAYS OF 6 DAY PERIOD
SUBJECT - D.A.
WD = WATER DRUNK
MIN = MINIMUM WATER INTAKE
Wox = WATER OF OXIDATION
BW = BODY WATER
URW = URINE WATER
MIN = MINIMUM URINE WATER
FEW = FECAL WATER
I W = INSENSIBLE WATER
WATER, CC PER DAY
2000
1800
1500
1200
900
600
300
0
WD 1000
URW 718
1845
MIN 984
Wox 440
BW 420
MIN 703
IW 1142
WD 837
URW 577
1878
MIN 835
Wox 362
BW 681
MIN 575
FEW 53
IW 1250
FASTING
-29° C
USAF EMERGENCY RATION-2
+22° C

FIGURE 17

COMPONENTS OF THE WATER EXCHANGE

(Calculated for lW - 1000, Caloric Output = 2500)

M.W.l	=	Minimum Water Intake	Wox.	=	Water of Oxidation
BW	=	Body Water	M.Ur.W.	=	Minimum Urine Water
ECW	=	Extracellular Water	l.W.	=	Insensible Water
ICW	=	Intracellular Water			

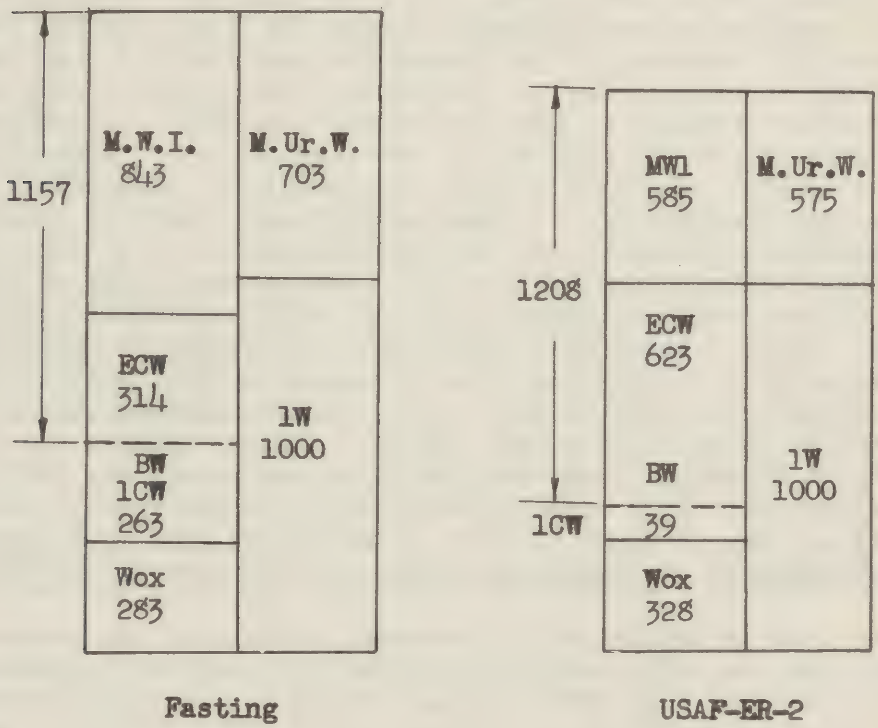


FIGURE 18

B. Role of Rations in Survival

CLOTHING VERSUS FOOD

Reference has already been made to the role of food or rations in survival (see Introduction). The fasting control studies in the cold chamber and in the Alaskan field trial demonstrate that food is of secondary importance to the adequacy of clothing and sleeping bag for survival at low ambient temperatures. In Table 45, data from the same two subjects during fasting are presented for comparison with the results obtained during consumption of the first developmental USAF emergency ration at ordinary room temperature and in the cold chamber. When adequate environmental protection was provided in the form of clothing and a sleeping bag, such that man's caloric expenditure was equivalent to that observed at normal room temperature, the total urine solutes, urine nitrogen and minimum urine water requirement, as well as gross physical capacity and psychomotor performance were not significantly influenced by the cold environmental temperature. The normal 11-oxycorticosteroid assays during the fasting study reflect the functional adequacy of the insulation provided and the consequent lack of environmental stress. Inasmuch as the subjects were adequately clothed while residing in the cold chamber at -29°C., the only significant exposure to the cold was in the inspired air. Although these negative results were anticipated, the functional adequacy of the experimental clothing had not been established under the conditions of continuous exposure to the cold for periods up to 10 days. A preliminary study in the cold chamber with current issue of Arctic flying clothes was terminated within 48 hours because of their inadequacy. Such a short term experiment did not permit any appraisal of nitrogen or water balance since a "steady metabolic state" had not been reached. Despite high initial morale and motivation, the experimental subjects abandoned the cold chamber because the inadequacy of clothing forced them to be active beyond the limit of their endurance. This occurred while eating approximately 2000 calories per day (2 units of P.E.R.) indicating that food cannot supplant adequate environmental protection for survival in the cold.

The lack of initiative in improving their lot, the greater discomfort from the cold, and deterioration in morale and physical capacity (Harvard Step Test) of the fasting subjects in contrast to the men eating rations of various caloric value (1000 to 3500) during the Alaskan field trial indicates however, that food assumes a role of relative importance in the cold environment. The body heat, capacity and strength for sustained work, and the maintenance of high morale as derived from food may be sufficient initially to prevent the castaway from freezing to death by enabling him to alter his immediate environment.

TABLE 45

	FASTING	EMERGENCY RATION - 1	
ENVIRONMENT	-29°C.	-29°C.	+20°C.
RATION, CALORIES	0	1948	1948
CHO, GMS.	0	318	318
PRO, GMS.	0	41.6	41.6
FAT, GMS.	0	57	57
CALORIC OUTPUT/DAY	3150	2915	3050
URINE			
NITROGEN, GMS.	10.12	8.73	7.81
N - BALANCE, GMS.	-10.12	-2.07	-1.15
TOTAL SOLUTES, m-osM	871	779	723
OSMOLAR CONC., osM/L	1.29	1.39	1.25
MINIMUM URINE WATER, cc.	597	505	493

WATER VERSUS FOOD

In order that the importance of water to the chances for survival be fully appreciated, a clinical description of the effects of "dehydration exhaustion" would seem appropriate. The need for water is not immediate, but it may arise early in the course of survival, depending upon the environmental temperature and the amount of physical activity. There is good agreement among observers who have written on the subject from laboratory or field experience that very rapid physical and psychological deterioration ensues in the hot environment after deprivation of water (3, 28).

A castaway may begin the survival experience in perfect physical condition and in good spirits, but if water is not available, thirst becomes noticeable and cheerfulness diminishes. When 3 to 5% of the B.W. is lost by deprivation of water, thirst is marked (6). "Later thirst becomes intolerable, discipline begins to suffer and the individual notices failing physical efficiency. An observer will see that his face is flushed, his coordination impaired and if he is marching, he begins to lag behind. Somewhat later, the soldier will be tormented with thirst; discipline may become impossible — even rifles and personal belongings may be thrown away. Physical deterioration will be so marked that efficient work is impossible and the soldier may become hysterical or suffer from hallucinations" (30). Peters has reported that a loss of 10% of the B.W. is totally disabling to men (25). "Finally, collapse will occur, and the soldier may faint. If he now stands up, he may faint again. . . . His life is now in danger if he is not given proper treatment, which consists of water, salt and shade, if available. This type of exhaustion will inevitably occur in the toughest man if his water supply is cut off. In the desert the whole process up to collapse may take only three or four hours.

"If measurements are made, it will be found that the soldier has a fast pulse and an abnormally high body temperature. His ability to handle the heat load is impaired. Near the point of collapse, his blood pressure while standing is too low to maintain adequate circulation to the brain and he may faint (orthostatic hypotension). Chemical measurements will show that water has disappeared from his blood so that he will have an abnormally high plasma protein and hemoglobin and usually a slightly elevated plasma chloride" (30).

From the above description, it is apparent that physical efficiency becomes impaired as dehydration progresses. In dogs death occurs, apparently from respiratory failure, when 25 to 40% of the body water has been lost (25, 9); this probably obtains for man. A man weighing 70 Kg. contains about 70 per cent or 49 Kg. of body water. If an expenditure of 25 - 40% of this is incompatible with life, then the survival period for thirsting is defined as 9 to 15 days (when 1300 cc. B.W. is lost/day) under the most favorable environmental conditions

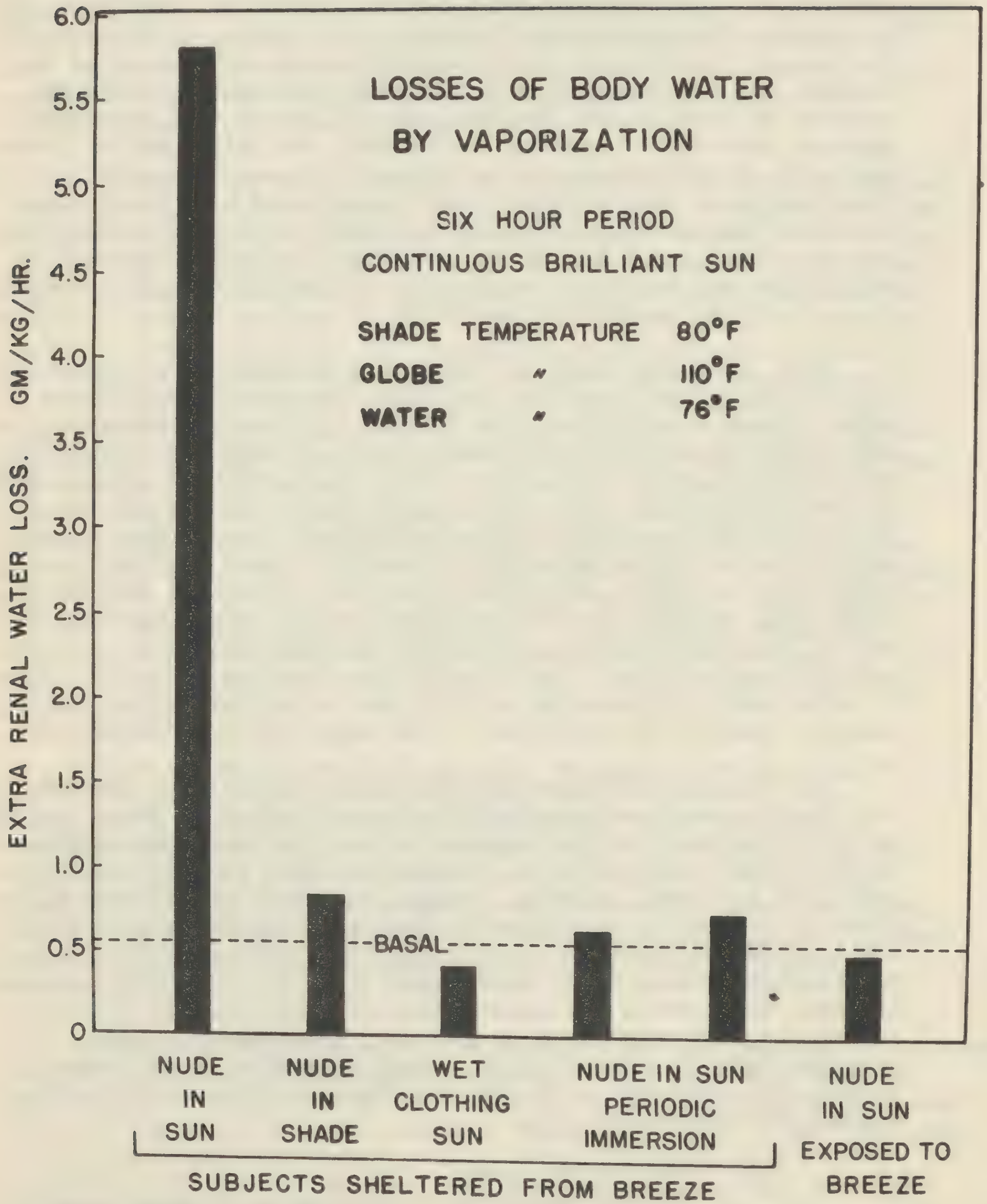
and with a minimum of physical activity. Thus deprivation of water is more serious than deprivation of food. "The resistance of the organism to the deprivation of food, i.e., until death, varies greatly. In man it may be assumed to vary from 17 to 76 days, (average 40 days), in the dog, which has been chiefly subjected to these studies, from 21 to 117 days" (31). The longest recorded survival of a man without water and food, under the conditions of the moderate temperature and humidity of a prison, is 18 days (32). The longest recorded period of survival at sea without water is 11 days (33). Twenty-two of 26 men from a detachment of troops survived 86 hours in the environment of a desert with strenuous physical activity. These men drank their own urine and the blood and urine of their horses in an attempt to quench their thirst (34). It is now known that drinking such concentrated body fluids does not counteract dehydration although it may temporarily relieve the dryness of the mouth and throat. In fact, the solute content of such fluids may aggravate dehydration by further drawing upon body water for their repeated elimination.

Thus, since survival for fasting is several times longer (40 days cf. 9-15 days) than for thirsting, the provision of water holds higher priority than that of food, and the advantages of the ration must be appraised in terms of the net effect of the ration upon water balance. It has been shown (5, 6, 9) that a small amount of pure carbohydrate (75 to 100 grams) may be substituted for a part of the minimum water intake, as defined for fasting, at no cost to the net water exchange. However, if more calories are needed for the arctic environment, it would seem more wise to include small amounts of protein and fat in the ration (approx. 5 and 10 grams respectively, for a 1000 calorie ration) to achieve maximum acceptability. The quantitative increase in the Min. Ur. W. as a result of including up to 5 gms. of protein in the ration does not justify its exclusion at the sacrifice of acceptability.

In reference to Figure 19 (5), it is obvious that the attention and great concern over an economical use of water by the kidney will be of little avail to the castaway unless the larger expenditure by way of the lungs and skin (insensible water loss and sweat) is held near its basal quantity. Since insensible expenditure of water is related to energy metabolism, it is recommended that in the tropics, the survivor should avoid physical activity as much as possible. Also, it is recommended that in hot weather measures be taken to decrease the vaporization of body water as much as is compatible with maintaining normal body temperature. Gamble suggests these measures include direct reduction of environmental warmth, or substituting for the vaporization of body water other process of heat removal (5):

1. Stay in the shade.
   (Direct reduction of environmental temperature)

2. Increase the cooling effect of breeze by removal of clothing. (Promotion of convection)



4752-K AML

FIGURE 19

3. Periodic immersion in the sea.
   (Promotion of conduction)

4. Wet clothing with sea water.
   (Vaporization of sea water in place of body water).

The quantitative effectiveness of these measures as determined in Gamble's field study is shown in Figure 19.

Requirements for survival may differ physiologically with the environment of the various geographical areas. A castaway may succumb to acute dehydration in the tropics long before starving to death. He may freeze to death long before dehydration or starvation would take its toll in the arctic. Thus, while water may be the critical factor to survival in the tropical environment, adequate protection against the cold is of fundamental importance in the arctic. However, food may assume relative importance in preventing the castaway from freezing to death by enabling him to alter his immediate environment and by permitting sustained physical activity.

The decision as to the most suitable quantity and composition of the ration depends upon the weight allowance for both food and water aboard aircraft and upon the environment.

	RATION PROVISION		WATER PROVISION	
Weight Allowance	Tropical	Arctic	Tropical	Arctic
800 gms.	100 gms CHO	100 gms CHO	700 cc.	700 cc.
1000 gms.	100 gms	220 gms CHO 5 gms PRO 10 gms FAT	900 cc.	800 cc.
1300 gms.	220 gms CHO 5 gms PRO 10 gms FAT	USAF-ER-2	1000 cc.	800 cc.

VII SUGGESTIONS FOR FURTHER STUDIES

The former extreme restriction in water supply available to a castaway led to the design of a life raft ration providing 100 grams of pure carbohydrate. The basis for this was the anti-ketogenic and protein sparing effects of carbohydrate which reduce the solute load requiring elimination in the urine, and thereby reduce the obligatory renal water expenditure. The studies herein reported have demonstrated that a ration containing a small amount of high quality protein does not increase the solute load presented to the kidneys above that associated with fasting if the caloric intake is adequate. The minimum renal water requirement for a ration providing approximately 2000 calories, derived from 40 to 50 grams of high quality protein, 55 or 75 grams of fat, and the remainder from carbohydrate, was less than that observed in the control fasting studies on the same subjects. However, the obligatory urine water expenditure during consumption of a pure carbohydrate ration was estimated by Gamble to be approximately only one half of that during fasting. The question arises - should the survivor be provided with more than 100 grams of carbohydrate per day (400 calories) to prevent ketosis and the physical inefficiency incidental to a marked caloric expenditure associated with the arctic environment? The answer to this question is essential to a definition of minimum requirements for survival in the Arctic. If more than 400 calories are necessary, the following suggestions for further studies are presented:

A. EXPERIMENTAL PLAN

1. Obtain control data on the <u>same</u> subjects whenever possible for each of these nutritional states:

    a. Fasting.

    b. Pure carbohydrate ration, 100 grams.

    c. Test ration.

2. Initial evaluation of test rations can be accomplished most easily and with the least hardship for the experimental subjects by conducting the studies at constant ordinary room temperature and humidity. Subsequent appraisal of a test ration, shown to be satisfactory at ordinary room temperature, should include confirmation of its adequacy in controlled, hot or cold environment chamber experiments, and ultimately in field trials. These confirmatory studies will serve primarily to demonstrate acceptability of the ration items under the environmental conditions and survival circumstances for which they are intended to be used.

3. The duration of the experimental phase should be a minimum of 10 days whenever possible to achieve a "steady metabolic state" and to permit measurable changes in physical capacity and morale.

4. In order that a single variable may be studied; namely, the ration, it is desirable to approximate constancy in caloric expenditure (e.g., 2500 calories per day) during the various control experiments. However, it will be noted that in the first investigation to be recommended, the variable is caloric expenditure (4500 calories per day) while the ration is 100 grams of pure carbohydrate.

5. Expression of results in terms of the "standard man" will be simplified if experimental subjects who weigh as near 70 Kg. as possible are selected. This eliminates the assumptions that caloric expenditure and the various components of the water exchange are proportional to the body weight.

6. In order to define the minimum water intake necessary to prevent dehydration, provide a constant ample supply (not abundant) of water, regulating the intake according to the anticipated extra-renal water losses in relation to the environment. Adjustment in the salt intake will be required for circumstances which provoke excessive sweating.

B. SEQUENCE OF FURTHER RATION STUDIES

Number	Ration	Caloric Output	Environment	Purpose
1.	100 gm. CHO	4500 Cal./day	-20°F	? Arctic Minimum
2.	Fasting	4500 Cal./day	+70°F	Control for (1)
3.	Fasting	2500 Cal./day	+90°F	Control for (5)
4.	100 gm. CHO	2500 Cal./day	+90°F	Control for (5)
5.	500 Cal., chiefly CHO, small am'ts of PRO & FAT	2500 Cal./day	+90°F	Test Ration (Tropical), metabolic studies
6.	500 Cal., same as (5)	Approx. 2500 Cal./day	Tropical Field Trial	Acceptability Test
7.	1000 Cal., same as (5)	Approx. 4500 Cal./day	-20° or -40°F.	Test Ration (Arctic)
8.	1000 Cal., 20 gm. PRO, 30 gm. FAT, q.s. CHO	2500 Cal./day	+70°F	"Unit" Ration for Rescue

C. RECOMMENDED LABORATORY PROCEDURES

1. Blood

a. Non-protein nitrogen.
b. Hematocrit.
c. Hemoglobin.
d. Serum CO_2 content (?blood pH).
e. KCNS space.

2. Urine

a. Total solutes (freezing point depression of undiluted urine).
b. Total nitrogen.
c. Ammonia, total acids, organic acid.
d. Routine urinalysis: sp. gr., pH, albumin, acetone, sugar, and microscopic examination.

3. Stool

a. Water content.

4. BMR, chest X-ray, EKG, concentration-dilution kidney function test - to appraise the initial physical state of the experimental subjects and to rule out pathology.

D. RECOMMENDED CALCULATIONS AND MEASUREMENTS
(See Corresponding Section in the Discussion of Methods)

1. Body weight - daily.

2. Nitrogen balance.

3. Caloric expenditure by correlating time - activity data with Haldane analyses on Douglas Bag collections.

4. Body substance catabolized.

5. Components of the water exchange - daily.

6. Ration acceptability - questionnaire.

7. Physical capacity - Harvard Step Test.

8. Subjective reactions - initiative, fatigue, discomfort, lassitude, nausea, morale, etc.

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IX. GLOSSARY OF SYMBOLS*

A. Rations

1. USAF-ER-1 = USAF Emergency Ration, Developmental No. 1 (29)
2. USAF-ER-2 = USAF Emergency Ration, Developmental No. 2 (31)
3. USAF-ER-3 = USAF Emergency Ration, Developmental No. 3 (33)
4. P.E.R. = Parachute Emergency Ration (27)
5. CHO = Carbohydrate (25)
6. PRO = Protein (25)
7. N = Nitrogen (42)

B. Water Balance

1. W.I. = Water Intake (51)
2. Min.W.I. = Minimum Water Intake (54)
3. I.W. = Insensible Water Loss (51)
4. Ur.Vol. = Urine Volume (51)
5. Ur.W. = Urine Water (51)
6. Min.Ur.W. = Minimum Urine Water (51)
7. Wox. = Water of Oxidation (53)
8. B.W. = Body Water (53)
9. I.C.W. = Intracellular Water (53)
10. E.C.W. = Extracellular Water (53)
11. Fe.W. = Fecal Water (53)

C. Energy Exchange

1. Cal/hr. = Calories per hour, metabolic cost (44)
2. R.Q. = Respiratory Quotient (43)
3. P.M.V. = Pulmonary Ventilation (43)
4. H_{cl} = Heat loss through the clothing (45)
5. E_l = Heat loss through evaporating moisture from the lungs (48)
6. E_s = Heat loss through evaporating moisture from the skin (48)
7. A = Heat loss through warming inspired air (48)
8. W = Energy lost in the performance of external work (49)

D. Laboratory Data

1. ΔT_f = Freezing point depression, °C. (51)
2. osM/L = Osmoles per liter, osmolar concentration (53)
3. m-osM = Milliosmoles, total solute output (53)
4. F.P. = Freezing Point (41)
5. N.P.N. = Non-protein Nitrogen (40)
6. Hgb = Hemoglobin (40)
7. RBC = Red Blood Count (40)
8. 11-ocs = 11-oxycorticosteroid-like substances (40)
9. 17-KS = 17-ketosteroids (40)

*Numbers in parentheses indicate page upon which symbol is discussed.